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Textbook of  
**Field Crops Production**  
Foodgrain Crops

Volume I



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# Rice

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Rice (*Oryza sativa* L.), grown in India and South east Asia is a plant of Asian origin. Archaeological findings of the Indus-Saraswati civilization point out that rice was eaten in the advanced Mesolithic or pre-Neolithic period (c. 8080  $\pm$  115 BC) at Chopani Mando. Rice grains were also found at Mahagara (c. 5440  $\pm$  240 BC) and rice husk was found to have been used as pottery temper at Koldiwal (c. 6570  $\pm$  210 BC). All these three locations are in central Uttar Pradesh (Nene, 2005). Rice was also found to be grown in Neolithic Chirand in North Bihar (2000-1300 BC) and in Hastinapur (1100-800 BC) and some other places (Randhawa, 1980). The Jeypore tract of Odisha has been established as the centre of origin of *Oryza sativa*, the cultivated rice in India (Mishra, 2009). The word *Oryza* is most likely of Indian origin (Vrihi – Sanskrit and ‘arise’ – Tamil) (Nene, 2005). No wonder 90% of the world’s area under rice is in Asia and also about 90% of world’s rice is produced and consumed in Asia. In 2009, rice was grown over about 150 million ha in the entire world, out of which 132 million ha was in Asia (Table 1.1). Five countries having more than 10 million ha rice area, namely India, China, Indonesia, Thailand and Bangladesh, are in South and Southeast Asia and make up a little over two-thirds of the total area under rice. Again, out of total world rice production of 685 million metric tonnes, 590 million metric tonnes was produced in Asia in 2009.

India, the country having the largest rice area in the world had only 40.5% of the productivity reached in the USA and 48.5% of that in China during 2009. The area, production and productivity of rice in different states of India is given in Table 1.2. A large number of factors such as drought, lodging, weeds, soil acidity/sodicity, poor soil fertility, insect-pests, diseases, rodents etc. are responsible for these low yields and their contribution to the yield loss varies from ecosystem to ecosystem. However, the major factor is too much or not enough water at some critical stage of the rice crop. Percentage irrigated area under rice in eastern India is only 30 as against nearly 100 in Punjab and Western Uttar Pradesh, the latter forms the backbone of country’s self-sufficiency in foodgrains. Also eastern India has country’s 90% area under rainfed uplands, where droughts occur frequently. High-yielding varieties with multiple disease and pest resistance for this region are yet not available and where available enough seed is not produced to meet the demand. The socio-

**Table 1.1** Area, production and yield of rice in major rice-producing countries (2009)

Continent/country	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)
<i>Asia</i>			
Bangladesh	11.4	47.7	4.2
China	29.9	196.7	6.6
India	41.9	133.7	3.2
Indonesia	12.9	64.4	5.0
Japan	1.6	10.6	6.5
Mynamar	8.0	32.7	4.1
Pakistan	2.9	10.3	3.6
Philippines	4.5	16.3	3.6
Thailand	11.0	31.5	2.9
Vietnam	7.4	38.9	5.2
Korea, Rep of	0.9	7.0	7.6
<i>Europe</i>			
Italy	0.24	1.5	6.3
Spain	0.12	0.9	7.5
Russian Fed.	0.18	0.9	5.1
<i>Africa</i>			
Egypt	0.75	7.5	10.0
<i>North America</i>			
USA	1.3	10.0	7.9
<i>South America</i>			
Brazil	2.9	12.7	4.4
World total	158.3	685.24	4.3

Source: FAI (2011)

economic situation in this part of the country is not good and rice farmers have very little funds of their own and the credit availability is also meagre. During the triennium ending 2008-09 the per caput income (₹/annum) was 45,114 in Punjab, while it was only ₹ 12,740 in Bihar. Similarly, during 2007-08 flow of institutional agriculture credit (₹/ha) was 46,593 in Punjab as against ₹ 8,880 in Bihar (NAAS, 2010). This keeps rate of application of fertilizer and other agricultural inputs very low and the potential of available rice varieties is not attained. For increasing the productivity of rice in India, this region deserves full attention of the state governments and scientists.

### TAXONOMY AND CLASSIFICATION

Cultivated rice belongs to family Poaceae (Graminae), sub-family Bamboosoideae, tribe Oryzeae. The genus *Oryza* has been divided into four species complexes: 1. Sativa complex, 2. Officinalis complex, 3. Meyeriana complex and 4. Ridley complex (Khush, 2005). The chromosome number, genomic composition and geographical distribution of different *Oryza* complexes are given in Table 1.3. The spikelet and its structure is the major criterion in species classification.



**Table 1.2** Rice area, productivity (clean rice) and fertilizer (N+P<sub>2</sub>O<sub>5</sub>+K<sub>2</sub>O) consumption in some states of India (2009-10)

State	Rice area (1,000 ha)	Productivity (tonnes/ha)	Fertilizer (kg N+P <sub>2</sub> O <sub>5</sub> + K <sub>2</sub> O/ha)
<i>North</i>			
Haryana	1,205	3.0	209.1
Himachal Pradesh	77	1.4	56.9
Jammu and Kashmir	260	1.9	98.2
Punjab	2,802	4.0	235.8
Uttar Pradesh	5,187	2.1	166.9
Uttarakhand	294	2.1	130.7
<i>South</i>			
Andhra Pradesh	3,441	3.1	221.4
Karnataka	1,487	2.5	166.4
Kerala	234	2.6	98.3
Tamil Nadu	1,846	3.1	205.5
<i>West</i>			
Gujarat	679	1.9	155.5
Madhya Pradesh	1,446	0.9	80.4
Chhattishgarh	3,671	1.1	94.5
Maharashtra	1,470	1.5	138.7
Rajasthan	151	1.5	47.1
<i>East</i>			
Arunachal Pradesh	122	1.8	3.0
Asom	2,496	1.7	60.8
Bihar	3,214	1.1	168.0
Jharkhand	995	1.5	99.1
Manipur	169	1.9	51.0
Mizoram	47	0.9	57.6
Meghalaya	108	1.9	10.9
Nagaland	169	1.4	2.3
Sikkim	13	1.9	Not available
Odisha	4,365	1.6	57.3
Tripura	246	2.6	48.1
West Bengal	5,630	2.5	167.8
Total (India)	41,918	2.1	127.2

Source: FAI (2011)

*Oryza sativa* complex (the cultivated rice) is briefly discussed. It has two cultivated species, namely *O. sativa* and *O. glaberrima*. *O. sativa*, the Asian rice is grown worldwide, while *O. glaberrima* Steud. is grown on limited acreage in a few African countries. The *O. sativa* has two wild species, namely *O. nivara* an annual and *O. rufipogon* a perennial (Sharma and Shastry, 1965). *O. meridionalis* (also named as *O. australiensis*) is distributed across tropical Australia. *O. glumaepatula* a wild species related to *O. rufipogon* is found in

**Table 1.3.** Chromosome number, genome composition and geographical distribution of *Oryza* species

Species	2n	Genome	Distribution
<i>Oryza sativa</i> complex			
<i>O. sativa</i> L.	24	AA	Worldwide
<i>O. nivara</i> Sharma & Shastry	24	AA	Tropical and Sub-tropical
<i>O. rufipogon</i> Griff.	24	AA	Tropical and Sub-tropical Asia, Tropical Australia
<i>O. breviligulata</i> A. Chev. & Rohr.	24	AA	Africa
<i>O. glaberrima</i> Steud.	24	AA	West Asia
<i>O. longistaminata</i> A. Chev & Rohr.	24	AA	Africa
<i>O. meridionalis</i> Ng	24	AA	Tropical Australia
<i>O. glumaepatula</i> Steud.	24	AA	South and Central America
<i>O. officinalis</i> complex			
<i>O. punctata</i> Kotschy ex Steud.	24,48	BB, BBCC	Africa
<i>O. minutata</i> J.S. Presl. ex C.B. Presl.	48	BBCC	Philippines and Papua New Guinea
<i>O. offinalis</i> Wall. ex Watt	24	CC	Tropical and Sub-tropical Asia and Tropical Australia
<i>O. rhizomatis</i> Vaughan	24	CC	Sri Lanka
<i>O. eichinegri</i> A.Peter	24	CC	South Asia and East Africa
<i>O. latifolia</i> Desv.	48	CCDD	South and Central America
<i>O. alta</i> Swallen	48	CCDD	South and Central America
<i>O. grandiglumis</i> (Deoll) Prod.	48	CCDD	South and Central America
<i>O. australiensis</i> Domin.	24	EE	Tropical Australia
<i>O. meyeriana</i> complex			
<i>O. granulata</i> Nees & Arn.ex Watt	24	GG	South and Southeast Asia
<i>O. meyeriana</i> (Zoll. & Meritzi) Baill.	24	GG	Southeast Asia
<i>O. ridleyi</i> complex			
<i>O. longiglumis</i> Jansen	48	HHJJ	Java,Indonesia and Papua New Guinea
<i>O. ridleyi</i> Hook.f.	48	HHJJ	South Asia
Unknown genomes			
<i>O. grachyantha</i> (A.Chev. & Rohr.)	24	FF	Africa
<i>O. schlechteri</i> Pilger	48	Unknown	Papua New Guinea

Source: Khush (2005)



Latin America. *O. glaberrima* is distinguished from *O. sativa* by its short, grounded ligules, panicles lacking secondary branches and almost glabrous lemma and palea. The perennial and annual relatives of *O. glaberrima* are *O. longistaminata* and *O. breviligulata* respectively. For a discussion on other *Oryza* complexes, reference may be please made to Khush (2005).

*O. glaberrima* was domesticated in Africa about 3,500 years ago. It was prone to lodging and its panicles had shattering problem. To overcome these problems, *O. sativa* was introduced in Africa some 450 years ago. *O. sativa* gave higher yields and has spread steadily in Africa. However, some *O. glaberrima* varieties, such as, CG 14 are more weed competitive, resistant to iron toxicity, drought, nematodes, waterlogging and major African rice diseases and pests. They also adapt better to acid soils and to soils low in phosphorus. Efforts are therefore underway to develop crosses between *O. glaberrima* and *O. sativa* since 1990's. These new rices are known as NERICA (New Rice for Africa). The best NERICA varieties combine the stress tolerance of *O. glaberrima* and high yield potential of *O. sativa* (Mohapatra, 2010).

The weedy types of rice have been given various names such as *O. fatua*/*O. spontanea* in Asia and *O. stapfil* in Africa. The weedy rices have generally red endosperm and are therefore known as red rice. Depending on location, these weedy types may be closely related to *O. rufipogon* and/or *O. nivara* in Asia and to *O. longistaminata* or *O. breviligulata* in Africa.

Cultivated varieties of *O. sativa* are further grouped into three ecotypes: *indica*, *japonica* and *javanica*. *Indicas* are grown throughout the tropics and subtropics. Traditional *indicas* are characterized by tall stature, weak stem, droopy leaves, high tillering and do not respond to high input conditions. *Japonicas* are limited to temperate zone. However, because of high returns, the International Rice Research Institute (IRRI) has developed two varieties of *japonica* suitable for tropics, which are NSIC Rc170 or IRRI 142 (now called MS11) and NSIC Rc220 or IRRI 152 for large-scale cultivation in the Philippines (Kang, 2010). *Japonicas* respond well to intensive crop management due to short stature and sturdy stem, narrow, erect and dark green leaves. *Javanicas* are grown mainly in parts of Indonesia. They have fewer tillers, tall stature with sturdy stem, long panicles and long bold grains.

### VARIETAL IMPROVEMENT

Systematic varietal improvement began at Rice Research Station, Dhaka (now in Bangladesh) in 1911 with pure line selections (Singh, 1999). Later on, rice breeding and genetic research work was taken up at many other centres simultaneously. During the second world war large-scale food shortage resulted in the establishment of the Central Rice Research Institute (CRRI) at Cuttack in 1946. This was the centre for *indica-japonica* hybridization programme. The  $F_2$  seed of these crosses was made available to different research stations. ADT 27 and Mahsuri in India and Malinga in Malaysia were developed under *indica-japonica* hybridization programme.

All India Coordinated Rice Improvement Project (AICRIP) was established in 1965 at Rajendranagar, Hyderabad. Meanwhile, the IRRI was established at



Los Banos in the Philippines. Introduction of Taichung Native 1 (TN 1) and IR 8 during 1965-66 proved a turning point in rice breeding. Utilizing these varieties, a good number of high-yielding varieties were developed in the seventies. At present, 125 rice research stations representing 28 state agricultural universities are working on all aspects of rice. Some of the popular varieties developed before 1960 are given in Table 1.4.

**Table 1.4** Some of the popular varieties developed before 1960 in India

State	Popular variety
Andhra Pradesh	MTU 1, MTU 15, HR 19
West Bengal	Chinsurah 7
Bombay	Kolamba strains
Madhya Pradesh	Hybrid 2, Hybrid 18, Dubraj
Tamil Nadu	GEB 24 m, Co 2, Co 25, Co 26, ASD 1
Odisha	T 141, SR 26 B
Punjab	Basmati 370
Uttar Pradesh	T 136, N 22

Source: Krishnaiah (1998)

Enhancing and stabilizing the grain yield potential with suitable plant type in different ecological conditions is the major objective of a plant breeding programme. For assured areas of irrigation and drainage a semi-dwarf plant (90-110 cm) with sturdy stem, high and synchronous tillering ability, relatively erect dark green leaves, and high grain number seems to perform better. In rainfed lowland situations plants with a height of 120-140 cm with sturdy stem perform better. Quick growing, early maturing, relatively taller plant performs well under upland conditions (Chang, 1972). In rice-based cropping systems varieties maturing in 90-110, 115-125 and 135-140 days fit well.

After grain yield, grain quality has been the most important consideration. If a variety has poor rough rice (paddy) appearance and its low milling outturn and texture and taste is not acceptable to consumers, it will have no future. Milled rice with complete translucent grain is preferred. The opaque areas in a translucent endosperm are known as white belly.

Rice possesses enormous variability for grain length. Preferences for grain shape (ratio of length and breadth) vary from place to place. A reasonably useful classification for evaluating the breeding lines for grain quality based on length, width and shape is given in Table 1.5.

**Table 1.5** Classification of grain quality based on length and shape of milled rice

Designation	Length (mm)	Scale	Shape	Length : width ratio	Scale
Extra long	7.50+	1	Slender	3.0+	1
Long	6.61-7.50	3	Medium	2.1-3.0	3
Medium	5.51-6.60	5	Bold	1.1-2.0	5
Short	-5.50	7	Round	-1.1	9

Source: Jennings *et al.* (1979)



Medium slender, medium bold, short bold and round-type grains without belly when milled at 14% moisture do not easily break and have high head rice recovery (percentage of unbroken rice and 3/4th size in a milled rice sample). High brown rice percentage and its colour are equally important. Varieties differ greatly in kind and intensity of aroma. Inheritance of aroma has been studied by several researchers.

Grain cooking and eating standards vary considerably from region to region. Milled rice with long slender translucent grain with or without aroma, high volume expansion during cooking (made up by linear kernel elongation), fluffiness (non-sticky and tender), firm texture of cooked kernel, appealing taste and longer shelf-life are preferred in the domestic and international market. Pusa 1121 is an example of high-yielding scented and foodgrain quality rice variety. In the *japonica*-growing regions, there is preference for sticky rice.

After the advent of semi-dwarf high-yielding varieties in the mid-sixties, rice breeding programme in the country was put on a sound footing. A good number of varieties combining earliness, resistance to biotic and abiotic stress and grain quality have been developed. Table 1.6 lists high-yielding rice varieties developed and available for different regions of India.

### Hybrid rice

Rice is a self-pollinated crop. In the absence of any cytoplasmic male-sterile (CMS) lines and restorer system the idea of hybrid rice did not come, until Chinese rice breeders found a sterile wild rice plant in Hunan province in mid-sixties and developed CMS lines utilizing the wild cytoplasm. This cytoplasm was named as wild abortive (WA). By mid-seventies utilizing the IRRI varieties, IR 24, IR 26 as restorers successful hybrids were released for commercial cultivation in China, giving 20-30% higher yield than their best local varieties. The CMS lines developed in China were also made available to other rice-growing countries through the IRRI in 1980. Chinese hybrids did not do well under Indian conditions due to poor quality grains, susceptibility to disease and pests and lower yield than the conventionally bred best varieties. Rice breeders in the IRRI and India developed their own CMS lines using WA cytoplasm. Some of the rice hybrids developed in India are listed in Table 1.7.

Hybrid rice development is a two-step process as shown in Fig. 1.1 and such hybrids are known as three-line hybrids.

Area under hybrid rice in India has increased from 10,000 ha in 1995 to 1,100,000 ha (1.1 million ha) (*Agriculture Today*, May 2009 issue), which is about 2.5% of the total area under rice in India. As a contrast more than 50% of area under rice in China is under hybrids (Barclay, 2007).

Chinese researchers are now developing single breeding step lines (known as two-line hybrids). These are called as super rice hybrids and yield on average 10% higher than three-line hybrids; or a 30-40% more yield than the conventional high-yielding rice varieties (Barclay, 2007).

### GM 'Golden Rice'

GM (Genetically modified) foods originate from a variety of plants, animals

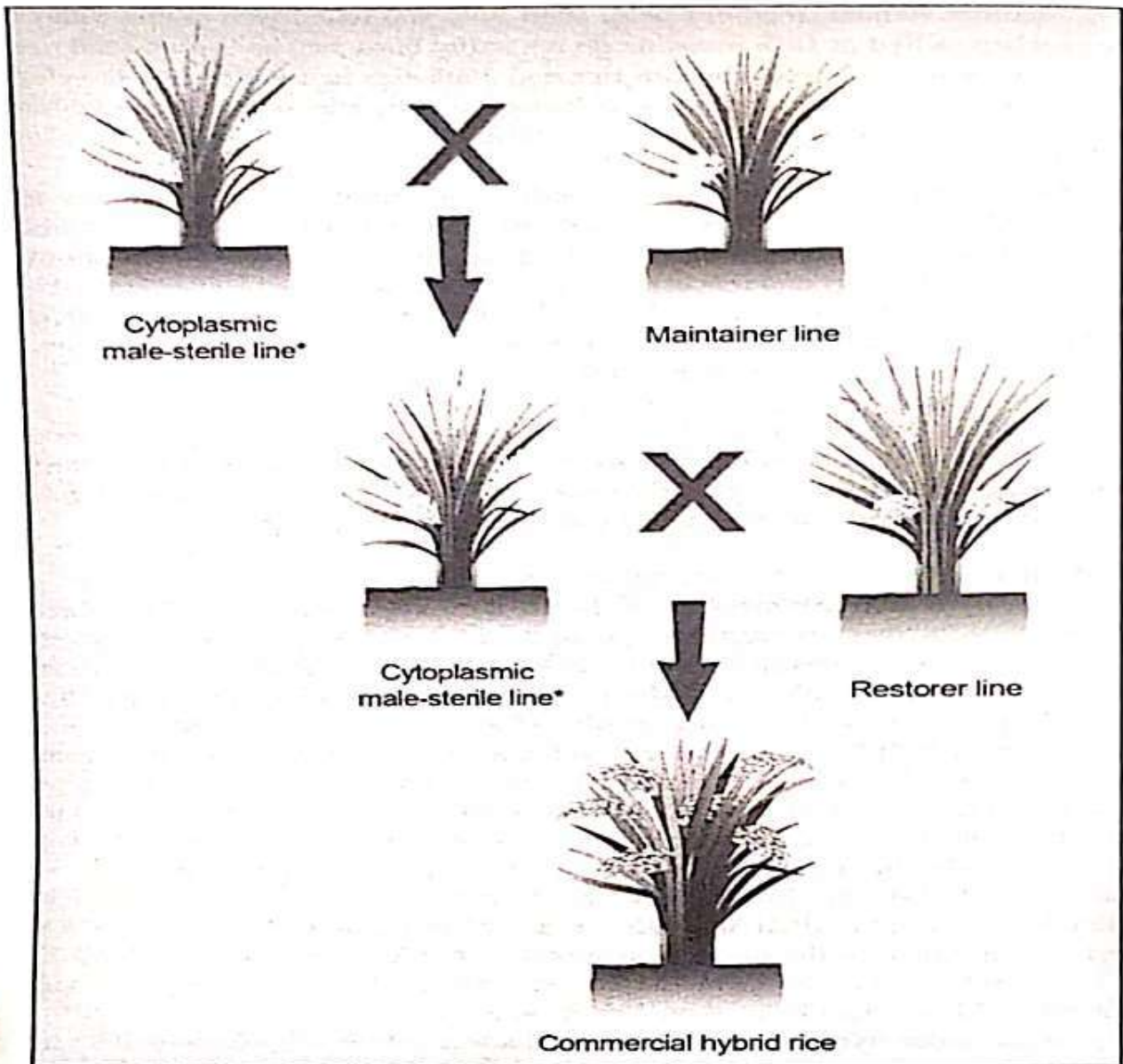


Fig. 1.1. Production of three-line hybrid rice varieties (Source: Barclay, 2007)

and micro-organisms as a result of recombinant DNA technology (Ammann, 2000), which involves transfer of genes from known species into the food-producing species. One of the well-known GM rice is 'Golden Rice', which has been engineered to express  $\beta$ -carotene by introducing a combination of genes that code for the biosynthetic pathway for production of pro-vitamin A ( $\beta$ -carotene) in the endosperm (Ye *et al.*, 2000). GM rice has also been developed



**Table 1.6** Popular high-yielding rice varieties for different ecosystems and rice-growing situations in India

Ecosystem or rice-growing situation	Varieties
Rainfed upland	Tulasi, Aditya, Prasanna, Rasi, Satya, Rudrama, PNR 381, Birsadhan101, Birsadhan 104, Birsadhan 105, Birsadhan 201, Birsadhan 202, Heera, Kanchan, Kalinga III, Annada, GR 2, GR 5, GR 6, GR 8, Himdhan, Nagardhan, VLK Dhan, VL Dhan 221, RP 2421, Himalaya 741, Himalaya 2216, Amrut, Mukti, IET 7564, Suvarna, Modan, Onam, JR 75, R 281-31-1, Tuljapur 4, Ratnagiri 73-1-41, Teena, Kranti, Ngoba, Parijat, Pathara, Kalyani II, Sattari, Neela, Rudra, Vanaprabha, Khandagiri, Nilagiri, Ghanteswari, Sneha, Patnai 23, Aswani, Renu, Saket 4, Narendradhan 18, Narendradhan 80, Narendradhan 97, Narendradhan 118, Khitish, Kiron, Bhupen, Anjali, Pantdhan 16, Somasila, Varalu, Danteswari, Birsadhan 108, Birsadhan 110, Chingam, Harsha, Rashmi, Bha Lum 1, Bha Lum 2, Naveen, Siddhanta, Vandana, Baranideep, PNR 519, ADT(R) 48, NDR 1045-2, Virendra, Shivam.
Rainfed shallow lowland	Manasarovar, Swarnadhan, Phalguna, Mandya Vijaya, Nandi, Swarna, Sambamahsuri, Pinakini, Krishnaveni, Thikkana, Chaitanya, Pothans, Orugallu, Sri Nanga, Sagarasamba, Simhapuri, Laksmi, Salivahana, Bahadur, Kushal, Ranjit, Manoharsali, Mahsuri, Moniram Katekijoha, Rangili, Bhogali, Pankaj, Savitri, Sita, Jayashree, Janaki, Radha, CR 1002, Rajashree, Kanak, Vaidehi, Hemavathi, Nathravathi, IET 7191, Abhilash Intan, KPH 2, Neerja, Rashmi, Kayamkulam, Shyamalu, Sotril 7, Kranti, Surekha, Mahamaya, Ratnagiri 2, SYE.75, SYE-ER 1, Darna, Ratnairi 3, R 374-11, Jagannath, NEH Megha Rice I, NEH Megha Rice 2, Rajeswari, Seema, Parijat, CR 1014, Jajati, Urbashi, Samalei, Pratap, Saradhi, Gauri, Daya, Mahalakshmi, Lakhmi, Savitri, Madhukar, Jaayalakshmi, Suresh, Dinesh, Biraj, Bipsa, IR 42, Dhanarasi, Deepti, Godavari, Surya, Tholakari, Vedagiri, Rajendra Mashuri 1, Birsamati, KMP5, Sharavathi, Lam Pnah 1, SKL 8, Shah Sarang1, Jagabandhu, ADT 44, Giri, Shashi, Ketekiojha.
Semi-deep and deep water situation	Amulya, Nalini, Jogen sabita, Biraj, Jaladhi I, Suha, Jaladhi 2, Vaidehi, Jalmagna, Rambha, Utkal Prabha, Manika, Mahalaxmi, Kanchan, Panidhan, FR 13A, Jallahri, Jalnidhi, Jalapriya, Jitendra, Madhukar, Chakia 59, Natina, Mandira, Mahalakshmi, Purendu, Bapatta Sannalu, Bhageerathi, Uphar, Hemavathi, Eriemaphou, Durga, Budeb, Mahanada.
Irrigated	Rasi, Vikas, Tella Hamsa, Prabhat, Abhaya, Rajendra, Divya, Sasyashree, Bhaddrakali, Suraksha, IR 64, Ajaya, Vikramarya, Vibhava, Satua, Saleem, Surekha, Kavya, Erramalleu, Pusa 2-21, Pusa 44, Gautam, CR 1002, Archna, Rajendradhan 201, Rajendradhan 202, Jaya, Vikram, Karjat 2, Karjat 3, Ratnagiri 3, Sugandha, Ambika, Jaya, Narmada, Ratna, IR 20, IR 36, HR 4, Gaur 10, GR 102, GR 103, HKR 102, Haryana Basmati, Tarori Basmati, Basmati 370, Pusa 44, Pusa Basmati 1, Kasturi PR 103,

Table 1.6 contd

**Table 1.6** *concluded*

Ecosystem or rice-growing situation	Varieties
	HKR 126, RP 732, Himalaya 732, Ranbir Basmati, Jhelum, K 78-13, SKAU 23, SKAU 27, Akash, Avinash, Karna, Mahaveer, Prakash, Vikram, Vidhava, Sonasali, IR 30864, Red Annapurna, Mandya Vani, Triveni, Jyothi, Pavizkhani, Athira, Kartika, Makom, Sabari, Jayathi, Kanchana, Swarnaprabha, Aishwarya, Aruna, Remya, Konakam, Mata Triveni, Kairali, Ruchi, Mahamaya, Patel 85, Madhuri Pawana, Sugandha, Punshi, Maniphouibi 1, Manephouibi 2, IR 8, PR 106, PR 109, PR 108, Basmati 385, PR 111, Bharatidasan, Jawahar, Aravinder, Punithavathi, Savitri, Pudukai Ponni, BK 79, BK 190, Mahisugandha, IR 50, TKM 9, PMK 1, ADT 36, ADT 37, IR 20, Co 41, Co 43, Co 44, TPS 1, MDU 2, MDU 3, ADT 39, ADT 42, JJ 92, ASD 17, White Ponni, Ponni, Paiyur 1, ADT 40, Co 42, Co 45, TRC Boro Dhan, Saket 4, Sarjoo 52, Narendradhan 359, Govind, Madhukar, Jayalakshmi, Suresh, Dinesh, Biraj, Bipsa, IR 42, Givind, Pantdhan 4, Pantdhan 6, Pantdhan 10, Pantdhan 12, Manhar, Narendradhan 2, Kunti, Lakhmi, Munal, Pusa Sugandh 2, Pusa Sugandh 3, Pusa Sugandh 4 (Pusa 1121), Pusa Sugandh 5 (Pusa 2511), PR 114, PR 116.
Saline areas	CST 71, Lunishree, CSR 10, Panvel 1, Panvel 2, Vytilla, Vytilla 3, Vytilla 4, CSR 5.
Alkaline areas: post-flood situation	(a) Early receding of floods: Pankaj, Biraj, Andrewsali, Prafulla. (b) Chronically flood-affected areas: Andrewsali, Biraj, Manoharsali, KMJ 1-19-1, KMJ 1-17-2, Gitesh, Prafulla. (c) Late receding of floods: Vikas, Heera, Luit, Kalinga III, Sattari.
Hilly regions	Pantdhan 1, Majhera 3, VL Dhan 39, VL Dhan 163, VL Dhan 206, VL Dhan 221.

*Sources:* Krishnaiah (1998), Siddiq (2006), Routray (2007), Singh (2006)

**Table 1.7** Some rice hybrids developed in India

Hybrid	Developed by	Duration (days)	Expected yield (tonnes/ha)
<i>Basmati type</i>			
PRH 10	IARI, New Delhi	130-135	6.0
Suruchi 5901	Mahyco	115	6.0
<i>Non-basmati type</i>			
DRRH 1	DRR, Hyderabad	125-130	7.0
APHR 1	Andhra Pradesh	130-130	7.0
APHR 2	Andhra Pradesh	130-135	7.5
Narendra Sankar Dhan 2	NDUAT, Faizabad	130-135	7.0
Pant Sankar Dhan 1	GBPUAT, Pantnagar	120-125	6.0
Pro-Agro	Pro-Agro Seed Co.	115-120	8.0
Mahyco 504	Mayhco Seed Co.	120-125	6.5
JK 6004	Ganga Kaveri Seed	120-125	6.0

*Major source:* Kumar *et al.* (2007)



that produces both  $\beta$ -carotene and ferritin. A total of seven genes have been introduced, four of which code for  $\beta$ -carotene and three allow the kernels to accumulate iron through ferritin (Potrykus *et al.*, 1996).

GM rice is yet to be accepted for human consumption in India and several other countries.

### **Aerobic rice**

In recent years, a new set of rice varieties known as 'Aerobic rices' have been developed by crossing drought-prone, low-yielding upland rice varieties and high-yielding lowland rice varieties. Again, the work was initially started in China and Brazil and was followed by the IRRI, Philippines and later in India. Some of the aerobic rice varieties are HD (Han Dao) 277, HD 297, HD 205 from China; Talento, Soberana and AN Cambara from Brazil; and Apo (IR 55423-01) from IRRI (Prasad, 2011). In India, University of Agricultural Sciences, Bengaluru, has developed an aerobic rice variety MAS (Marker-assisted selection) 946-1. However in on-farm trials conducted by the Indian Agricultural Research Institute (IARI) in Bulandshahr (Uttar Pradesh) a number of IARI varieties, such as Pusa Hybrid 10, Pusa Sugandh 3, Pusa Sugandh 4 and Pusa Sugandh 5 were found to be as good as IRRI variety Apo (Singh and Chinnusamy, 2007).

## **THE PLANT**

Like other annuals of Gramineae, rice plant has jointed stem (known as culm), rather flat leaves and terminal panicles. A brief description of various plant parts follows (for more details, *see* Prasad, 1999).

### **Roots**

Soon after sowing, rice seed gives out seminal roots from the radicle. These are of temporary nature. The real functional roots are secondary adventitious that are produced from the lower nodes of the culm. The root system is fibrous and generally remains in the top 20 cm of soil in the case of transplanted rice. In direct-seeded rice the roots go deeper depending on the availability of water and soil physical properties.

### **Stem**

The rice stem or culm is hollow and is made up of nodes and internodes. Each node bears a leaf and a bud, which may grow into a shoot or tiller. Stems are shorter (about 90 cm) in direct-seeded upland rice varieties than in transplanted lowland rice varieties (about 130 cm). Primary tillers grow out of the main culm in alternate order. Emergence of secondary tillers from primary tillers also follows the same pattern. Tillering potential of rice varieties differs considerably. Hybrids have more profused tillering habit than even the high-yielding varieties. Tillering continues during the vegetative growth (up to 60 days after transplanting). Some of these tillers die during the reproductive phase due to competition for water and nutrients.

**Leaf**

Rice leaf consists of a long sheath and a blade. In most rice varieties the leaf sheath may almost completely cover the upper internode. At the juncture of the sheath and blade is a papery structure known as ligule and two auricles, the latter encircle the internode.

**Panicle**

The inflorescence of rice plant is born on terminal shoot and is known as panicle. It is terminate type and at maturity is droopy in nature. Rice panicle is branched and the branches bear spikelets. The extent to which the panicle and a part of the uppermost internode extends beyond the flag leaf decides upon the exertion of the panicle and this character differs between varieties. Direct-seeded upland low-yielding varieties have generally 3-4 panicles/plant, while the lowland high-yielding varieties have 6-10 panicles/plant.

*Spikelet:* A spikelet is the floral unit and consists of two sterile lemmas, a lemma, a palea and the flower. Rice grain is the ripened ovary with lemma and palea firmly adhered to it. The lemma and palea with other smaller components form the hull and are removed in shelling rice for consumption. The rice fruit is a caryopsis in which single seed is fused with the wall of the ovary (pericarp). The seed consists of endosperm and an embryo. The embryo is very small and is found on the ventral side of the caryopsis.

Yoshida *et al.* (1972) observed that short and stiff stem, upright and compact tiller, profused tillering, thick, short, small and erect leaf and heavier and longer panicles are the characteristics that impact high yield in rice varieties.

**Growth stages**

The duration of a rice plant is nearly equally divided into vegetative and reproductive phases, each of about 50-60 days. In direct-seeded rice the entire vegetative phase is in the field, while in transplanted rice it is about 40% (20-25 days) in the nursery and 60% in the field. Reproductive phase consists of panicle initiation, panicle emergence, flowering, grain filling, milk or milk dough and ripening. Vegetative lag phase, also known as photoperiod-sensitive phase (PSP), is present only in long-duration varieties and is between the end of vegetative stage and the start of the panicle-initiation stage; its duration may last 10-20 days or even more.

**RICE ECOSYSTEMS**

Rice is grown on a wide variety of climate-soil-hydrology regimes, which are grouped into various 'rice ecosystems' or 'rice agroecological zones'. In India rice is grown in all the states and union territories; from Srinagar in the north to Kanya Kumari in the south and from Arunachal Pradesh in the east to Rajasthan in the west. The rainfall varies from about 700 mm per annum to 2,000 mm per annum and above, received mostly in a few months (June-September) by south-west monsoon. The eastern coastal area of the peninsular India receives rains also during October-February by north-east monsoons.



rather more in this part of the year than in June-September as in the rest of the country.

A very broad based classification of rice environments or ecosystems used in India includes six rice ecosystems, namely irrigated (transplanted) *kharif*, irrigated (transplanted) *rabi* season, rainfed lowland, rainfed upland, deep water and coastal lowland areas. Regions coming under these ecosystems, expected yield, cultural practices and constraints to production are given in Table 1.8. Irrigated rice ecosystems grown on bunded fields that retain water to assure flooded conditions, make up about 44% of the global rice area. The rainfed lowlands ecosystems comprise about 45% of the global rice area, while the rainfed upland rice ecosystems make up most of the rest 11%, the area under deep water ecosystems being very small.

### RICE SOILS

The wide range of agroclimatic conditions indicates an equally wide variety of soils. Moorman (1978) observed that the most important soil sub-orders on which rice is grown are: Aquepts, Aquepts, Orchepts, Tropepts, Aqualfs and Aquults (Table 1.9). As regards texture, rice is grown on loamy sands in Punjab to heavy clay loams or clays in Andhra Pradesh and some other states.

#### Special features of submerged soil profile

Whatever may be the soil type, one important characteristic of rice soils is that they remain submerged at least for some time during the growth period of the crop. Oxygen concentration in submerged soils gets considerably lowered. This is measured as redox potential. Redox potential in some soils as affected by duration of submergence is shown in Fig. 1.2. The submergence leads to

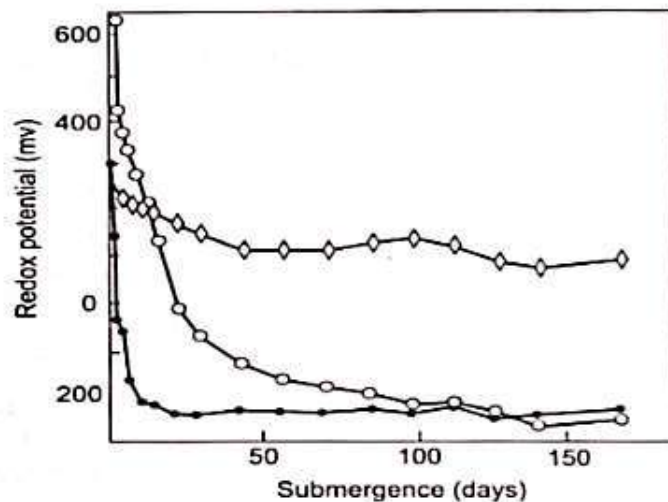


Fig. 1.2 Effect of submergence on redox potential in rice soils.

● Sandy loam 3.9% OM, 0.65% Fe; ○ clay 2.9% OM, 4.1% Fe; ◇ clay loam 1.1% OM, 1.13% Fe (Source: Ponnampetuma, 1981)

**Table 1.8** Broad based rice ecosystems in India and their important features (approximate area in India in parentheses)

Ecosystem	Region	Yield (tonnes/ha)	Cultural practices	Constraints to production
Irrigated wet season ( <i>khari</i> )	Punjab, Haryana Western UP and Southern India (16 million ha)	4-8	Bunding, puddling, transplanting	1. Occasional drought if tubewell water not available. 2. Micronutrient deficiencies 3. Weeds 4. Moderate disease/pest problem
Irrigated dry season ( <i>rabi</i> )	Eastern and Southern India (4 million ha)	3-5	Bunding, puddling, transplanting	1. Occasional drought if irrigation water not available 2. Micronutrient deficiencies 3. Weeds
Rainfed lowland (max. water depth-tillering to flowering 30 cm-1 m)	East India (Odisha, eastern UP, north Bihar, Assam, West Bengal, Jharkhand, Chhattisgarh (13 million ha)	>2	Bunding, puddling, transplanting	1. Flood/drought 2. Heavy incidence of diseases and pests 3. Weeds too much 4. Problem in fertilizer application
Rainfed upland (Max. water depth-tillering to flowering 0-30 cm)	Eastern and NE India (6 million ha)	1	Unbunded direct seeded	1. Drought/floods 2. Incidence of diseases and pests 3. Weeds too much 4. Poor soil fertility
Deep water (Max. water depth from tillering to flowering 1 m-6 m)	Eastern India (4 million ha)	1	Broadcast in dry unbunded fields before onset of monsoon	1. Diseases and pests 2. Unavailability of high-yielding varieties 3. Poor soil fertility 4. Fertilizer application problematic
Coastal low lands (saline)	West Bengal, Odisha, AP, TN, Kerala (1 million ha)	1	Direct seeded Transplanted	1. Salinity

UP, Uttar Pradesh; AP, Andhra Pradesh; TN, Tamil Nadu

Source: Widawsky and O'Toole (1996); Ramasamy *et al.*(1996), Das (2006)



**Table 1.9** Major rice-growing soils

Order	Sub-orders		
	Of major importance	Of local importance	Of minor importance
Alfisols	Aqualfs Ustalfs(a)	Udalfs	Xeralfs
Aridisols	-	-	Orthids(b), Argids(b)
Entisols	Aquepts	Fluvents	Orthents, Psamments
Histosols	-	-	Hemists, Saprists
Inceptisols	Aquepts, Orchepts Tropepts	-	Audepts
Mollisols	-	Aquolls	Udolls
Oxisols	-	-	Orthox, Ustox
Spodosols	-	-	Aquods
Ultisols	Aquults, Udults	Humults	Ustults
Vertisols	-	Uderts Usterts	Torrerts Xerertsb

a, Aquic sub-group only; b, under irrigation

Source: Moorman (1978)

gradual depletion of oxygen in the soil and this causes reduction of a number of nutrient ions such as nitrates, sulphates, iron, manganese etc. (Patrick and Mahapatra, 1968). A number of chemical reactions follow submergence, which affect rice plant growth. Some of these are:

- Increase in pH of acid soils and reduction in pH of sodic soils
  - Reduction in redox potential (reduction in concentration of  $O_2$ )
  - Reduction of nitrates to  $N_2O$  or  $N_2$  (denitrification)
  - Reduction of sulphate to sulphide resulting in sulphide toxicity; reported from highly reduced soils in Japan.
  - Reduction of  $Mn^{+4}$  to  $Mn^{+2}$  and  $Fe^{+3}$  to  $Fe^{+2}$  resulting in Mn and Fe toxicity in rice; reported from some areas in Odisha.
  - Increased availability of native soil P due to release of occluded P.
- For more information on submerged soils, refer to Ponnampuruma (1981).

### GROWING SEASONS

Rice-growing seasons vary in different parts of India, depending on temperature, rainfall and other local climatic conditions. In general, there are three seasons of growing rice in India. These are *aus* or autumn rice, *aman* or winter rice and *boro* or spring/summer rice. In the north-eastern and southern region, rice is grown in all the three seasons. In the eastern and southern regions two crops of rice are taken in a year. But in the north and western regions where winter temperatures are fairly low only one crop of rice is taken during *kharif* season. Rice cropping seasons in states are given in Table 1.10.

**Table 1.10** Rice-cropping seasons in different states of India

State	Local name of season	Period
Andhra Pradesh	<i>Sarwa, Abi</i>	May-Jun to Oct-Nov
	<i>Dalwa</i>	Nov-Dec to Apr-May
	<i>Tabi</i>	Dec-Jan to Apr-May
Asom	<i>Ahu</i>	Apr-May to Aug-Sep
	<i>Sali</i>	Jun-Jul to Nov-Dec
	<i>Boro</i>	Nov-Dec to Apr
Bihar, Eastern Uttar Pradesh	<i>Kharif</i>	Jun-Jul to Nov-Dec
	<i>Rabi</i>	Mar to Jun
Jammu and Kashmir	<i>Kharif</i>	Mar-Apr to Sep-Dec
Karnataka	<i>Haine</i>	Jun to Nov-Dec
Kerala	<i>Viruppa</i>	Apr to Sep
	<i>Mundakan</i>	Sep-Oct to Jan-Feb
	<i>Poonja</i>	Dec-Jan to Apr
Odisha	<i>Beali</i>	May-Jun to Sep-Oct
	<i>Sarad</i>	Jun-Jul to Nov-Dec
	<i>Dalua</i>	Dec-Jan to Apr-May
Tamil Nadu	<i>Swarnavari</i>	May to Sep
	<i>Kar, Kuruvai</i>	Jun to Sep
	<i>Samba</i>	Jul to Jan-Feb
	<i>Thaladi</i>	Oct to Feb-Mar
	<i>Pishanam, Karthigal Navarai, Manavari</i>	Oct to Mar Jan to May
West Bengal	<i>Aus</i>	Apr-May to Aug-Sep
	<i>Aman</i>	Jun-Jul to Nov-Dec
	<i>Boro</i>	Dec-Jan to Apr-May
Gujarat, Haryana, Himachal Pradesh, Madhya Pradesh Punjab, Rajasthan, Western Uttar Pradesh	<i>Kharif</i>	Jun-Jul to Oct-Nov

Source: Adapted from Rao (1985)

There is some variation in sowing and harvesting time of rice during different seasons in different parts of the country. *Aus* crop is generally sown in May-June and harvested in September-October, *aman* crop is sown in June-July and harvested in November-December and *boro* crop is sown in December-January and harvested in March-April. *Aus* and *aman* rice together (*kharif* rice) constitute more than 95% of the total rice area in the country, while the rest is contributed by summer rice.

### CULTIVATION METHODS

Rice is generally grown by dry or wet cultivation methods, which are briefly described here.



### **Dry cultivation/direct-seeding**

Dry system of rice cultivation is followed in uplands. Uplands are characterized by aerobic soil and attempt is made to impound water. Upland rice is grown on both level and sloping fields that are not bunded and are prepared and seeded dry and the crop depends upon rainfall for its water requirement. Mahapatra and Patnaik (1982) defined upland rice as the rice that may have no standing water on the soil surface 48 hours after cessation of rain or irrigation. This system of cultivation is followed in almost all the rice-growing states in India but is mainly confined to tracts that do not have adequate irrigation facilities. The land is ploughed several times in summer to get the necessary tilth and sowing of rice is usually done in May-June in the case of the crop dependent on south-west monsoon and in September for the crop dependent on north-east monsoon. Upland rice is called *aus* in West Bengal, *aus* or *ashu* in Asom, *beali* in Odisha, *bhadai* or *kuari* in Uttar Pradesh.

Sowing of the dry and semi-dry crop should be done in right time for getting maximum yield. Yield of the late-sown crop has been found to be invariably low. Three methods are commonly followed in sowing dry and semi-dry crop. These are broadcasting, drilling or sowing in furrows behind a country plough, and dibbling. In general, a seed rate of 30-50 kg/ha is required for drilling, while 60-100 kg/ha is required for broadcasting. A row spacing of 15-20 cm is optimum for upland rice. Some special operations performed in upland rice culture in some regions are discussed here (Tripathy and Mohapatra, 2007).

**Beushening:** *Beushening* is practiced in direct-seeded lowland rice in Odisha, Madhya Pradesh, Bihar and to a lesser extent in West Bengal, Asom and Uttar Pradesh to control weeds, optimize crop stand and provide soil aeration (Nayak and Garanayak, 2000). The practice involves cross ploughing the young crop four to six weeks after sowing with a light country plough in 5-10 cm standing water once or twice depending upon the density of weeds and crop stand; if there are too many weeds, it is followed by planking. This operation is called, *beushen* in Odisha and *biasi* in Madhya Pradesh. Following this operation the crop is weeded, thinned and the gaps are filled with the uprooted seedlings. This operation is called *khelua*. In some areas, *khelua* is done a week or 10 days after *beushening*. *Beushening* has been observed to reduce the straw yield and increase the grain yield by checking vegetative growth. Another term associated with gap filling is *batia*. *Batia* is a lump of soil anchoring a few plants. *Batias* are placed in the patches of field, where plant population is low. *Batia* is done on the same day, when *beushening* is done.

### **Direct seeding as a component of conservation agriculture**

Direct seeding is also being promoted as a component of conservation agriculture. Results from a on-farm trial in Ballia district of Uttar Pradesh showed that zero tilled direct-seeded rice gave significantly higher grain yield, reduced input cost and resulted in higher net returns (Singh *et al.*, 2009) (Table 1.11).

### **Ahu + bao mixed cropping in direct-seeded rice**

Mixed sowing of an early-duration drought-tolerant rice (*ahu*) variety and



**Table 1.11** Rice grain yield, cost of inputs and net profit in rice using different seeding techniques in on-farm trials in Ballia district of Uttar Pradesh

Seeding techniques	Grain (tonnes/ha)	Cost (₹/ha)					Total	Net return (₹/ha)
		Crop establishment	Seed	Fertilizer	Herbicides	Irrigation		
CT-TPR	3.87 <sup>b</sup>	2,655	900	2,565	405	1,755	8,280	11,925
RT-DSR	4.40 <sup>a</sup>	1,980	585	2,430	945	1,485	7,425	18,020
Zt-DSR	4.72 <sup>a</sup>	1,035	495	2,475	990	1,350	6,345	21,730

<sup>1</sup>Grain yield values followed by a different letter differ significantly @ P=0.05

CT-TPR: Conventional till (puddle) transplanted rice.

RT-DSR (Reduced-tillage direct-seeded rice): 2 to 4 dry tillages followed by planking; rice direct seeded on soil at optimum moisture using a zero-till seed drill in rows 18-20 cm apart.

RT-DSR (Zero-till direct seeded rice): Field irrigated to obtain optimum soil moisture for sowing, glyphosate/paraquat applied prior to seeding, rice direct seeded with a zero-till seed drill 7-10 dys before the onset of monsoon.

Original data in US \$; converted to ₹ taking 1 US\$ = ₹ 53.

Source: Singh *et al.* (2009)

a long-duration submergence tolerant rice (*baa*) variety is one option to overcome the uncertainty of flood occurrence. In the event of an early season flood, *ahu* rice may perish or yield little depending upon the duration and the depth of the flood water. *Baa* variety, however, continues to grow well. Some of the *ahu* genotypes are Gunj *ahu*, Koijapuri, Panjasai, Vandana, Guni *ahu* and Iharjat, while some of the *baa* genotypes are Bagagotha, Badam, Sonjul, NDR 900032, Durga and Meghraj. The combined grain yield from *ahu-baa* mixed cropping is expected to be 3 tonnes/ha.

### Wet cultivation/transplanting

In the wet system of cultivation, the crop is grown under wet season right from the start. In this system the field is brought to a soil puddle by repeated ploughings with 5-7 cm standing water. Rice fields with sandy to sandy-loam soil are ploughed in summer and again ploughed once or twice after letting in water to get the requisite puddle. Heavy soils of clayey nature are not generally opened in summer. After getting the requisite puddle, rice seedlings are transplanted or sprouted seeds are direct seeded. Puddling offers a number of advantages. These are (i) all weeds, which otherwise compete with rice plant for nutrients are killed and buried, (ii) the infiltration rate of water is reduced and water-retaining capacity of soil increases, (iii) the soft mud facilitates transplanting, (iv) the germinated seeds and seedlings are established in soft mud easily, (v) plant population becomes more assured, and (vi) availability of Fe and P increases and N is conserved better.

In transplanted rice cultivation, the first step is to have a nursery for raising the seedlings. There are three methods of raising rice seedlings, namely dry seedbed, wet seedbed and dapog method.



**Dry nursery:** Dry nursery is invariably prepared in areas where sufficient supply of moisture is assured through rainfall and where soil is sufficiently friable to retain moisture. In this method the field is ploughed repeatedly to a fine tilth and raised beds of 4 to 5 cm height, 1 to 1.5 m width and of convenient length are prepared keeping 30 cm wide channel in between. A seed rate of 2.5-3 kg/100 m<sup>2</sup> of nursery is appropriate.

**Wet nursery:** Wet nurseries are generally raised in areas with assured supply of irrigation. It is the best method for obtaining well-grown seedlings within a short period. For wet seedbed nursery, land is first ploughed under dry or moist conditions and then puddled by ploughing. After this, beds are prepared as discussed for dry nursery and sprouted seeds are either broadcast or sown in rows. Seed rate is the same as for dry nursery. For getting sprouted seeds, the seeds are soaked in ordinary water for 24 hours, incubated for 36 to 48 hours in a warm shady place and are never allowed to dry up by occasional moistening the seeds.

**Dapog method:** This method of seedling raising is commonly prevalent in the Philippines and has been introduced in India. The essential feature of this method is to have a very thick nursery seeding without any contact with the soil. Raised beds are prepared similar to wet nursery. The beds are covered with banana leaves (mid-rib removed) or empty cement/fertilizer bags or polythene sheets to prevent the roots of seedlings from coming in contact with soil. A wall of 5.0 to 7.6 cm high is made of strips of banana leaves on the four sides of the bed to keep the seeds in place after they are sown. Pre-germinated seeds at the rate of 3 kg/m<sup>2</sup> are sown uniformly on the beds. Water is splashed on the germinating seeds and the seeds are pressed down slightly by hand or light wooden plank in the morning and afternoon for 3 to 6 days. This prevents exposure of roots to the air and helps germinated seeds to remain in touch with each other and with the ground. For 3 to 4 days the seedlings are kept moist by sprinkling water. Seedlings become ready for transplanting within 12 to 14 days, regardless of duration of the variety. Fertilizer is not needed since the seedlings are nourished by nutrients in the seed.

#### **Date of transplanting/planting during *kharif***

Time of planting is the most important factor influencing the yield of a crop. Performance of a variety entirely depends upon the time of its planting. In general, transplanting in the first fortnight of July gives best yield in *kharif*. Delay in planting by 15-20 days from 16 July reduced the yield by 15 to 20% in Bankura, West Bengal, while two months delay in planting reduced the yield by 50 to 74% in Titabar, Asom and Samolkot, Andhra Pradesh respectively (Pillai, 1958).

In the North-western India, however, June transplanting was found better. For example, at Srinagar transplanting in the first fortnight of June was found to be optimum (Bali *et al.*, 1993, 1995). Crop transplanted beyond mid-June was exposed to low temperature (23.6°C and 12.5°C mean maximum and minimum) at flowering stage from the last week of August to the first week of September, whereas earlier sown crop showed flowering when temperature was



better for fertilization. Similarly at Kaul, Haryana early planting on 14 June gave significantly higher yield than normal planting in first week of July. Some data are presented in Table 1.12. For normal planting 21-25 days old seedlings are recommended.

**Table 1.12** Effect of date of transplanting on grain yield of *kharif* rice

Location	Date of planting	Grain (q/ha)	CD (P=0.05)	Variety
Shalimar (J&K)	14 June	53.6	2.1	K 39, K 343, K 448
	21 June	49.4		
	28 June	36.3		
	5 July	12.6		
Kaul (Haryana)	15 June	66.5	2.4	Jaya, HKR-20
	5 July	61.6		
	25 July	47.1		
Titabar (Asom)	20 July	45.0	1.99	IET 8002, IET 8021, IET 9188, IET 7946 IET 7251, IET 6666 Andrew Sali
	5 August	41.6		
	29 August	36.6		
	20 September	22.3		
	25 July	58.1		
DRR (Hyderabad)	5 August	50.0	1.99	Pro-Agro 103 APHR 2, DRRH 1
	15 August	38.5		

Source: Nayak and Gananayak (2000)

#### Date of transplanting/planting during *rabi*

Experiments for standardization of planting time during *rabi* season are limited. Trials carried out in Asom indicated that planting of tall *indica* rice in the last week of December was ideal for high yield in *boro* crop (Pillai, 1958). Ghosh (1968) from Chinsurah, West Bengal also reported that the best time of planting for tall *indica* rice during *rabi* was end of December to mid-January. For timely transplanting in wet season, 25-30 days old seedlings are ideal, while for delayed dry season transplanting 45-50 days old seedlings are better.

#### Age of seedling for late planting

Due to aberrant weather conditions and/or intensive cropping system transplanting of rice is often taken up late even beyond the critical period of planting. Under such a situation economically viable yield may not be possible without adoption of some special measures to compensate the loss due to delay in planting. Gill and Shahi (1987) from Kapurthala reported that 65 days old seedlings gave 10 and 31% higher yield than 45 and 30 days old seedlings under late-planted condition. Older seedlings grew vigorously, accumulated more dry matter, showed higher spikelet fertility, panicle weight and 1,000-grain weight. Sixty days old seedlings showed early 50% flowering and maturity and escaped from low temperature, whereas 30 days old seedlings did not flower and 45 days one did not exhibit complete panicle exertion under late transplanting.



**Spacing**

In Uttar Pradesh, Varma (1972) from a 2 years study at Varanasi with high-yielding varieties stated that the optimum spacing was 20 cm × 15 cm. Sharma and Warsi (1987) from Faizabad reported that for cv. Sarju 52 all the three spacings tried, viz. 20 cm × 10 cm, 27 cm × 10 cm and 20 cm × 15 cm, were equally good. Sewaram *et al.* (1973) working with high-yielding varieties for two years at Karnal reported that spacings of 15 cm × 15 cm, 15 cm × 20 cm and 15 cm × 30 cm were equally good. Thus, in general 20 cm × 10 cm, 20 cm × 15 cm or 15 cm × 15 cm spacings are ideal.

**Seedling/hill**

For realizing the yield potential of high-yielding varieties of rice, 2-3 seedlings/hill are generally recommended. In rice hybrids where the tillering is more profuse 1-2 seedlings/hill are sufficient.

**Depth of transplanting**

Since rice transplanting is generally done by hand, depth of transplanting rice seedlings is 2-4 cm, depending upon the extent of puddling done and the time lapse between puddling and transplanting. Very shallow transplanting results in poor seedling establishment and increased seedling mortality. Also if very shallow transplanting is done some seedlings get uprooted on irrigation or due to heavy rains and float on the surface of water and ultimately die.

**Double transplanting**

This involves transplanting rice into a secondary nursery with relatively large area than primary nursery before final transplanting in the main field. This becomes necessary when main field is not available due to early flood or delayed onset of monsoon. For double transplanting, nursery should be sown early in May. Seedlings of 21 to 30 days age are transplanted in the secondary nursery at a spacing of 15 cm × 10 cm (67 hills/m<sup>2</sup>). Fertilizer, 20 kg N and 10 kg each of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O/ha is to be applied in the second nursery bed. Seedlings from the second nursery should be uprooted after 21 to 30 days and transplanted in the main field. Thus the age of seedlings transplanted in the main field is 60 to 70 days. Photo-sensitive varieties, such as Prafulla are preferred for double transplanting. The cultures CNB 1257-95 and RP 4347-P50p102-1 are reported to perform better than Prafulla (Routray, 2007) and may yield more than 4 tonnes/ha. The recommended fertilizer dose is 60 kg N and 40 kg each of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O/ha.

**System of rice intensification**

It was developed in 1980's by a French priest Fr S.J. Henri de Lailanie in Madagascar (Africa) and has been supported by CGIAR International Institute for Food, Agriculture and Development (CIFAD), USA. The main features of system of rice intensification (SRI) are:

- Planting young (8-10 days old) seedlings.
- Planting a single seedling per hill.

- Widely spaced square planting — 25 cm × 25 cm or even 50 cm × 50 cm.
- One to two manual or mechanical weedings 10-12 days after transplanting.
- Application of organic manures.
- Optimizing soil moisture during vegetative, flowering and grain filling. No flood irrigation.

In India work on SRI was first initiated at the Tamil Nadu Agricultural University, Coimbatore and was followed by Andhra Pradesh. Some farmers in these states have adopted SRI. It is also catching up in Uttarakhand (VPKAS, 2006) and in some other states. The major advantages are a lower seed rate (7.5 kg/ha), lesser irrigation (Table 1.13) and higher grain yield (Vijayakumar *et al.*, 2004; Kediya and Dimri, 2009). For more information on SRI, refer to Senthil *et al.* (2009).

### Aerobic rice system

Aerobic rice system (ARS) is a new rice production system in which rice is grown under non-puddled, non-flooded and non-saturated soil conditions (Prasad, 2011). In ARS, rice is direct seeded on a dry bed and irrigation is applied at an interval maintaining the soil moisture at 0-40 KPa. Such water management is also known as AWD (alternate wet and dry) and the soil is partially aerobic during most of the growing season. Again this system was initially developed in northern China, but is finding favour in Bangladesh and even in India. This system reduces irrigation water needs considerably (Table 1.13).

**Table 1.13** Water needs for different systems of rice cultivation including aerobic rice

Cultivation method	Water needs (ha-mm)	Grain yield (tonnes/ha)	Water saving over conventional (%)	Water-use efficiency (kg grain/ha-mm)
Conventional (continuous flooding 5-10 cm)	1,500-4,000	5.0-6.0	-	2.5-3.0
Alternate wetting and drying	1,000-1,200	5.5-6.5	15-30	5.4-5.5
SRI (system of rice intensification)	1,200-1,400	7.0-8.0	20-25	5.7-5.8
Aerobic rice (irrigated on soil dryness to hair crack formation)	800- 1,000	4.5-5.5	30-70	5.5-5.6

Source: Ghosh (2008)

### Choice of crop establishment method

A number of criteria as shown in Fig. 1.3 determine the choice of crop establishment in rice.

### Rice ratooning

Rice ratooning is practiced in some pockets of Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and Uttar Pradesh. Ratooning is the ability of rice plants to generate from stubbles left from the harvest of the first crop. No crop establishment operation is required. About 40 kg N and 20 kg K<sub>2</sub>O/ha is to be applied at 3 and 25 days after the harvest of the first crop.



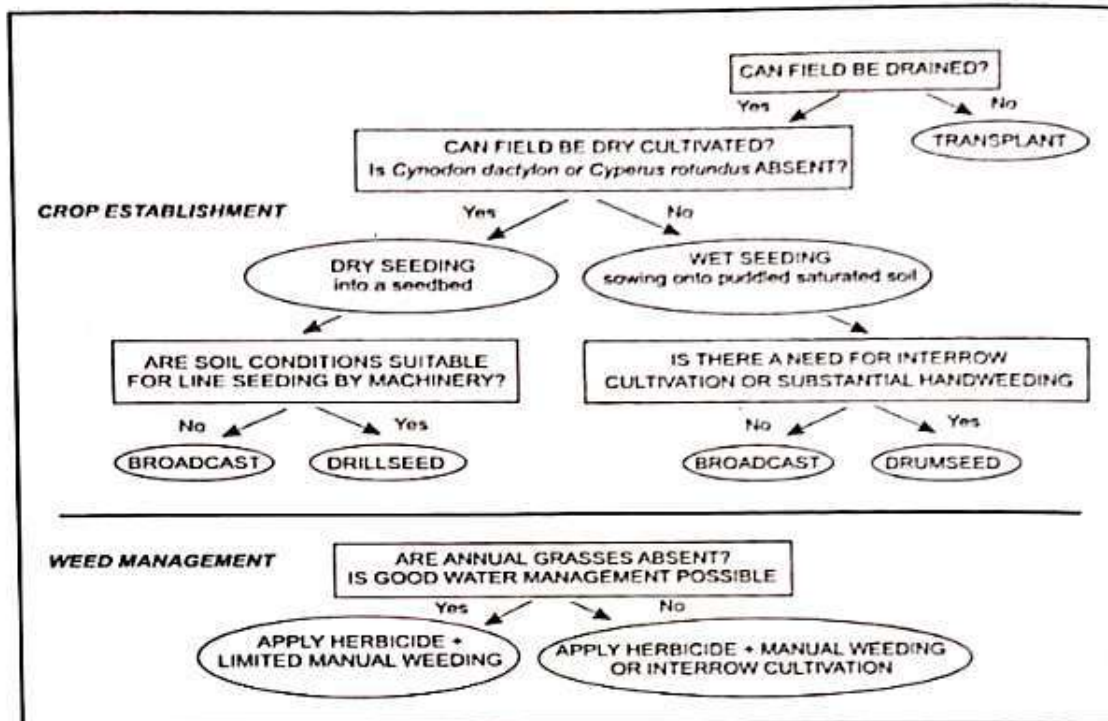


Fig. 1.3 Illustrative decision tree for adoption of direct-seeding with respect to favourable rainfed lowland rice (Source : Ripple (IRRC), Volume 2 (No. 4) pp. 3 (2007)

A manual weeding by a rack weeder/finger weeder is required 15-20 days after the harvest of the first crop. Under good agronomic management a ratoon crop gives a grain yield of about 2.7 tonnes/ha in 60-70 days, which is about 40% of the main crop. Some of the varieties responding to ratooning are Swarna, Ranjit, Rajshree, IR 8, IR 36, IR 72, Indira, Sashi, Mashuri, Savitri, Naveen, Tapaswini, Annada (Meher and Poonam, 2008).

In the mid-altitude areas of Meghalaya the first crop of rice is grown during spring-summer (April and August), during which period about 1,400 mm rainfall is received. About 800 mm rainfall is received during August and November, but a successful second crop is not possible due to the early onset of low temperature ( $<15^{\circ}\text{C}$ ), which leads to panicle sterility. Ratooning under such conditions saves considerable time, labour and inputs and makes possible a successful second crop. For this purpose, the culms of the rice plants should be cut at harvest of the first crop at 10 cm above-ground level leaving at least one active node intact. Some data on the relative productivity of the second transplanted vs ratooned crop are given in Table 1.14, and showed that ratoon crop gave 5.4 to 30.6% higher grain yield. Variety Vivek Dhan 82 was not suitable for ratooning and showed a yield reduction of -77.1%. So for ratooning in rice choice of right variety is very important.

**Table 1.14** Relative yield (tonnes/ha) of the main crop and a second transplanted and ratoon crop at Umiam (Meghalaya)

Variety	Main crop	Second transplanted	Ratoon crop
IR 64	4.32	2.76	3.22 (16.7)
Sahasarang	4.03	2.53	3.30 (30.4)
Aerobic rice (IR 72176)	4.21	2.37	2.50 (5.4)
Krishna Hamsa	4.05	1.68	1.81 (7.7)
Bhalum 1	2.79	2.18	2.30 (5.5)
Vivek Dhan 82	3.05	3.72	0.85 (-77.1)
CD (P=0.05)	0.38	0.31	0.33

Figures in parentheses indicate percentage increase over second transplanted crop  
 Source: Das *et al.* (2010)

### NUTRIENT MANAGEMENT

Adequate supply of essential plant nutrients is a must for getting good yield of rice. This is particularly true for high-yielding varieties and hybrids. In India and for that matter in the entire Asia fertilizer N mostly urea has received more attention (Prasad, 1998) than phosphorus and potassium fertilizers but balanced fertilization is the key. When we harvest a tonne (1,000 kg) of rice grain, we remove from soil about 15-31 kg N, 1-5 kg P and 8-35 kg K and 1-3 kg S/ha (Dobermann *et al.*, 1998) along with a few grams of each of the micronutrients. Good nutrient management is the key to good harvest. Good response of rice to N, P and K fertilization has been reported from all regions of the country and some data from on-farm trials are given in Table 1.15.

**Table 1.15** Response of rice to NPK fertilization in different regions of India

Region	Trials (Nos)	Control (tonnes/ha) Av. (Range)	Response (kg grain/kg nutrient)		
			Nitrogen Av. (Range)	Phosphorus Av. (Range)	Potassium Av. (Range)
<i>Kharif rice</i>					
Eastern	340 <sup>1</sup>	2.1(1.6-3.2)	11.7(5.8-16.7)	17.2(10.4-25.7)	19.4(7.9-40.0)
Southern	282	3.5(2.7-4.5)	9.7(2.9-18.0)	13.4(9.6-15.9)	12.3(10.0-16.4)
Northern	253	2.8(1.2-4.1)	10.1(4.8-15.3)	11.3(5.9-16.3)	7.4(4.2-11.4)
<i>Rabi rice</i>					
Eastern	94	2.4(2.0-2.7)	13.9(10.4-20.9)	18.7(15.0-24.1)	17.4(14.7-21.8)
Southern	262	3.3(2.4-3.6)	6.5(3.2-8.5)	10.9(9.8-14.6)	10.6(7.9-16.0)

<sup>1</sup> Eastern region includes states of West Bengal, Odisha, Chhattisgarh and Jharkhand; Southern region includes Andhra Pradesh, Karnataka, Tamil Nadu and Kerala; Northern region includes states of Punjab, Haryana, Uttar Pradesh and Uttarakhand.

Source: Indian Agricultural Statistics Research Institute, New Delhi (Data from PDCSR, Modipuram).



### Nitrogen

Rice responds well to nitrogen and a large number of reports are available (Prasad, 1996). A dose of 100-150 kg N/ha is generally recommended for high-yielding varieties of rice. Hybrids, where yield potential is 8-10 tonnes/ha, will need still higher doses of N (180-200 kg N/ha). A thumb rule will be 20 kg N/tonne of rough rice. Dose of N is also determined by the duration of rice variety and soil texture; higher levels are needed for medium-duration high-yielding varieties and for lighter (sandy to sandy loam) soils.

When fertilizer N is applied to soil (urea is taken as the example) it undergoes several changes as shown in Fig. 1.4. When surface applied on a soil having pH 7 or above, a substantial part (8-20%) of applied N could be lost due to ammonia volatilization (Prasad *et al.*, 1999a). In rice fields where the soil remains submerged during most of the growth cycle of crop and reduced conditions prevail due to lack of oxygen, several species of bacteria, e.g. S-oxidizing bacteria (*Thiobacillus thiooxidans*) use nitrate as a source of  $O_2$  and consequently reduce it to  $N_2$  or  $N_2O$ . This process is known as denitrification. It is considered as an important mechanism of N loss in rice paddies. In a laboratory study, Prasad and Lakhdive (1969) showed that about 80% of applied  $NO_3^-$ -N was lost in 72 hours due to denitrification. Denitrification losses are most severe under alternate flooded and drained conditions, because when drained conditions prevail nitrates are formed, which are lost under submergence. In a laboratory study, Rajale and Prasad (1972) showed that 3 cycles of alternate flooded and drained conditions could result in as much as 95% loss of applied urea N. Of various solid N fertilizers, urea is most susceptible to run-off losses when it is surface broadcast. This is because urea is a highly soluble, non-polar (neither + nor -) organic molecule and cannot be retained by soil particles. As a contrast  $NH_4^+$  in ammonium sulphate/ammonium

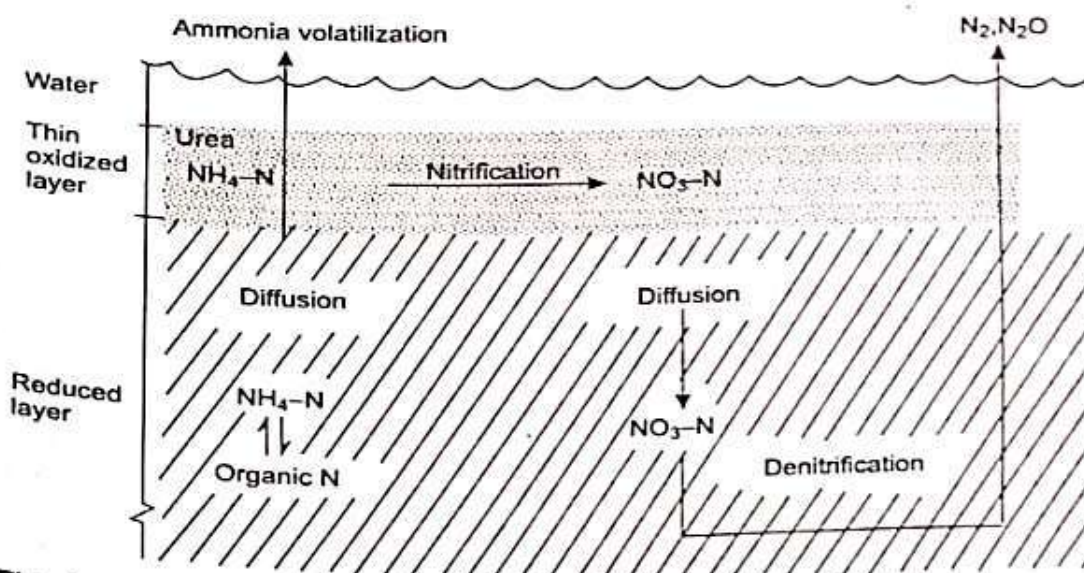


Fig. 1.4 Nitrogen dynamics in rice soils



phosphate/ammonium chloride even when applied to moist soil surface gets a chance to get adsorbed on the exchange complex of clay particles.

Considerable N in upland crops could be lost by leaching but again actual measurements are difficult. On the other hand in lowland rice conditions leaching losses of N may not exceed 1% (Patil *et al.*, 1990).

Nitrogen loss mechanism that has so far not received due attention is N lost through foliage and other plant parts (Patron *et al.*, 1988). Mosier *et al.* (1990) even suggested that young rice plants may facilitate the efflux of N<sub>2</sub> and N<sub>2</sub>O from the soil to the atmosphere.

Immobilization of mineral N occurs only when high C : N ratio materials are applied. In general, there is to and fro movement of N between soil organic N and applied mineral N. This has been proved by <sup>15</sup>N studies. In a field study, Goswami *et al.* (1988) found that as much as 31.2% applied N is immobilized. Only a small fraction of immobilized N becomes available to succeeding crop. In the rice-wheat system study by Goswami *et al.* (1998) only 4.6% of N applied to rice became available to succeeding wheat.

#### **Management practices for high N-use efficiency**

Nitrogen-use efficiency (NUE) can be increased by split application, deep placement and use of nitrification inhibitors and slow-release N fertilizers (Prasad, 1996).

*Split application:* Split application of N for increasing NUE is well established. When large amounts of N are applied at a time, say all basal, N efficiency is the lowest. Application of N should match the crop needs for N. Two split doses are recommended for short- and medium-duration varieties, while 3 split doses are recommended for long-duration ones. More splits are also recommended for sandy soils. For example, in rice, a yield advantage of 3.7 q/ha in *kharif* and 4.8 q/ha in *rabi* was obtained by 3 split applications as compared to a single application (Rao and Mahapatra, 1978).

Synchronization of fertilizer nitrogen application with crop needs is the best way to increase nitrogen-use efficiency. A simple handy, ever-lasting pocket tool like leaf colour chart (LCC) is now available at an affordable price. LCC is made up of high quality plastic material and consists of 6 strips of different shades of green from pale green marked as 1 to dark green marked as 6. Fertilizer nitrogen has to be applied when the colour of the youngest fully expanded leaf matches number 3 or 4 of the LCC. At one time 30 kg N/ha is to be applied. In on-farm trials in Punjab during 2008 and 2009, a saving of 44 to 69 kg N/ha could be possible with the use of LCC (Bijay-Singh, 2008).

*Deep placement:* Deep placement has received considerable importance in the case of phosphate fertilizer, but it is equally important in the case of N. Ammonia volatilization can be almost prevented by deep placement of fertilizer N (Prakasa Rao and Bhat, 1984). Deep placement of N is specially important in rice, because placement in the reduced zone can prevent or at least retard the formation of nitrates and their subsequent loss by denitrification.

*Nitrification inhibitors:* These chemicals can retard the nitrification process in soil and thereby reduce the N loss by leaching and denitrification. A number



of chemicals have been reported to have nitrification inhibiting properties. The chemicals most widely tested are: N-Serve (2-chloro 6 (trichloromethyl) pyridine), AM (2-amino-4-chloro-6 methyl pyrimidine), DCD (dicyandiamide) and ST (Sulphathiazole) (Prasad and Power, 1995). Increased rice yields and increased NUE in India has been reported for N-Serve, AM, ST and DCD (Reddy and Prasad, 1977; Sudhakara and Prasad, 1986). In addition, Reddy and Prasad (1975), Thomas and Prasad (1983) and Prasad *et al.* (1993) reported nitrification-inhibiting properties of neem (*Azadirachta indica* A. Juss.) seed extract. A technique of coating urea prills with neem oil micro emulsion was developed at the Indian Agricultural Research Institute, New Delhi (Prasad *et al.*, 1999b) and this technique or a modification of it is being used by a number of fertilizer manufacturers in India for making neem-coated urea (NCU). In on-farm trials in Punjab, Haryana, Uttar Pradesh and Delhi, an increase of 6 to 14% in grain yield and 3-5% in PFP<sub>N</sub> (partial factor productivity of nitrogen) by rice over prilled urea was recorded (Prasad, 2007a) (Table 1.16).

**Table 1.16** Relative efficiency of neem-coated urea (NCU) and urea for rice in on-farm trials

Location	No. of trials	Grain (tonnes/ha)		PFP <sub>N</sub>	
		Urea	NCU	Urea	NCU
Delhi	9	4.5	4.9	37.5	40.8
Punjab	45	4.9	5.2	40.8	43.3
Haryana and Uttar Pradesh	88	4.3	4.9	35.8	40.8

Source: Prasad (2007a)

**Slow-release N fertilizers:** These are of two kinds, namely (i) coated conventional fertilizers such as sulphur-coated urea (SCU), polymer-coated urea (PCU), and (ii) chemicals with inherent slow N release properties such as IBDU (isobutylidene diurea), ureaform etc. (Prasad *et al.*, 1971b). Ureaform and IBDU are urea-aldehyde condensates. Slow-release N fertilizers release N slowly and therefore allow its uptake before it is lost. It is their high cost that has not permitted their wider use. Ureaform is also known as turf fertilizer, and is widely used in the USA for fertilizing lawns.

**Urea supergranules:** These are based on the principle of chinese mudball technique. Small amounts of fertilizer N are placed inside a moist mudball by making a hole and sealing it. Mudballs are then dried and stored for placement in rice paddies. Urea supergranules (USGs) or large-size urea pellets come in different shapes and sizes; the most popular are 1 g (1 cm diameter) granules. These have been widely tested in India and the Philippines and have been found to increase the efficiency of fertilizer N by 20-30% under lowland rice conditions (Kumar *et al.*, 1990; Prasad *et al.*, 1989). USGs hold considerable promise for rice. The only problem is in their placement and no low-cost USG placement equipment is yet available although many have been developed and tested.



### Phosphorus

Phosphorus content in most Indian soils is within 200-800 ppm P (Khanna and Pathak, 1982); the range of organic P as % of total P is 10-30%. This is in contrast to nitrogen, where 90% or more is present in organic form. Therefore, most of P research in India and elsewhere is directed towards inorganic P, which makes up a major part of total P. Nevertheless contribution of organic P towards meeting crop requirement should not be overlooked particularly in tropics where the rate of decomposition of soil organic matter (SOM) is fast. Sharply (1985) also pointed out that organically bound P is important in plant nutrition in tropical soils, particularly where little fertilizer is used. Vij *et al.* (1997) reported higher mineralization of added plant and soil organic phosphorus under submerged conditions than under field capacity conditions.

About 80% of Indian soils are low to medium in available phosphorus (Motsara, 2002) and response to P application is expected for most crops. However, it is generally believed that rice responds lesser to P fertilizers as compared to upland crops on the same soil (De Dutta, 1981). This is due to increased availability of reductant soluble and occluded Fe-P under submergence (Patrick and Mahapatra, 1968). However, this is not true and in red, red and yellow, lateritic and coastal soils, which occur in eastern, north-eastern and southern states the response to phosphorus may be more than to N (Table 1.15 ). Kirk *et al.* (1998) pointed out that phosphorus deficiency is important in drought-prone environments because the mobility of P decreases sharply as soil dries. Furthermore even in rice-rice rotation, Dobermann *et al.* (1998) point out that although yield response to P was small in the earlier years of green revolution, phosphorus became the first deficient nutrient in long-term experiments after a few years of intensive cropping and it takes a little longer for K deficiencies to show up.

In rice-wheat cropping system, Saggat *et al.* (1985) found that at Ludhiana an application of 60 kg  $P_2O_5$ /ha to wheat was sufficient to meet the P requirement of the cropping system and therefore the general recommendation in Punjab has been to apply adequate P in wheat and skip P application in rice. However, Kolar and Grewal (1989) also from Ludhiana reported that application of 30 kg  $P_2O_5$ /ha to both rice and wheat gave higher production than application of 60 kg  $P_2O_5$ /ha to wheat only. Recent data from the on-farm trials conducted under the auspices of the Project Directorate for Farming Systems Research, Modipuram also clearly showed that both rice and wheat responded well to P fertilization; in fact response of rice to P was higher than of wheat in Punjab, Uttar Pradesh and Bihar (Prasad, 2007b). Also response to P was more with NK fertilization than with N fertilization, showing the need for balanced fertilization.

#### Agrotechniques for increasing phosphorus efficiency

*Time of application:* Application of P is generally recommended at final puddling before transplanting/final ploughing or at broadcasting in the case of direct-seeded rice; however, in the case of non-availability of fertilizer in time, it can be top-dressed within 30 days of transplanting and at the most may be



extended to 40 days on medium soils. On a highly P-deficit clay soil, delayed application of P resulted in 85% of the maximum rice yield in warm wet season (Katyal, 1978). These recommendations apply for P fertilizers having water-soluble P such as superphosphate and DAP. For ground rockphosphate, which is recommended for direct use on acid soils, application 3-4 weeks prior to transplanting has been found to be more useful (Patnaik and Mandal, 1982).

*Method of application:* The general practice is to broadcast P fertilizers just before final puddling in the case of transplanted rice and final ploughing in the case of direct-seeded rice. Dipping of roots of rice seedlings in P-slurry has also been found reasonably good (Katyal, 1978; Rabindra and Deshpande, 1980).

*Source of phosphorus:* Most P fertilizers marketed and used in India with the exception of nitrophosphates contain almost all of their P in water-soluble form. Considerable research on the evaluation of nitrophosphates has been done and extensively reviewed (Prasad *et al.*, 1971a; Prasad and Dixit, 1976). In general, for rice, P component of nitrophosphate should not make much difference. Some workers have indicated lower efficiency of nitrophosphates due to nitrate-N component. However, when applied as a source of P (30-60 kg  $P_2O_5$ /ha) the  $NO_3-N$  component in nitrophosphates is a small fraction of total N applied.

There has been considerable interest in the direct use of rockphosphate (RP) in rice specially on acid soils. This is because 60% of the 122-136 million tonnes of rockphosphate in India is considered unsuitable for use as raw material for manufacturing fertilizer (Jaggi, 1986; Dev, 1998). Because of its low P content (15-20%  $P_2O_5$ ) and low reactivity (Bhujbal and Mistry, 1981) as compared to single superphosphate its efficiency on acid soil is reported to be 65-134% (Suhrawardy *et al.*, 1980; Mahapatra and Patnaik, 1982). Rockphosphate needs to be generally applied 3-4 weeks before transplanting and should be incorporated in soil for better results. Some workers also recommend higher rates of application as compared to water-soluble P fertilizer. Higher efficiency of rockphosphate in acid soils is due to lesser P fixation. There are some reports that even on neutral and above neutral soils rockphosphate is as good as superphosphate for rice (Mehrotra, 1969; Ramaswamy and Arunachalam, 1983). Particle size of rockphosphate is an important property that affects its efficiency. For example, Ramaswamy and Arunachalam (1983) found that efficiency of rockphosphate was 55% (as compared to SSP) for 60 mesh material as compared to 77% for 100 mesh material. Other practices recommended for increasing the efficiency of rockphosphate include: mixing with compost (Mathur, 1980) or applying along with incorporation of organic residues, incubating with phosphate-solubilizing bacteria and mixing with pyrites (Sharma *et al.*, 2009; Sharma and Prasad, 1996).

### **Potassium**

Total potassium content in soils ranges from 0.35 to 4.65% (Sekhon, 1999) and about 50% of Indian soils are low to medium in available (1 M ammonium acetate exchangeable) K (Motsara, 2002). Since a major contribution to K



supply to plants is made by non-exchangeable K (NEK), its estimation along with that of exchangeable K is also being recommended for a better estimate of K-supplying capacity of a soil (Srinivasa Rao *et al.*, 2001). Further in recent years information obtained from GIS (Geographic information system) survey has been used to demarcate soils having different levels of NEK (Srinivasa Rao *et al.*, 2010).

In general, red, red and yellow, lateritic and coastal soils, which occur in eastern, north-eastern and southern states (the traditional rice regions), are deficient in K and a good response to K fertilization has been reported (Table 1.15). On the other hand, response to K in non-traditional rice region of north central and north-western region is generally lower. However, the intensive rice-wheat cropping system producing 8 to 15 tonnes grain/ha/year removes 150 to 300 kg K/ha/year, and these soils are gradually becoming poorer in K. For example, researchers at the Narendra Deva University of Agriculture and Technology, Faizabad, have shown that over a period of 30 years the decline in rice yield with nitrogen alone was 108 kg/ha/year. However, when K was applied along with N the yield reduction was only 89 kg/ha/year and this was further reduced to 39 kg/ha/year when both P and K were applied along with N (Table 1.17). Thus adequate K fertilization of rice is required all over the country.

Response of *kharif* rice to K may generally be higher than *rabi* rice (Mahapatra and Prasad, 1970). This could partly be due to the fact that incidence of disease in rice is more during *kharif* season. Potassium application reduces the severity of bacterial diseases of rice (Devadath and Padmanabhan, 1971; Padhi and Misra, 1971). Severity of fungal diseases such as brown leaf spot, *Cercospora* leaf spot, sheath blight, stem rot and *Helminthosporium* sp. is also reported to be reduced by K application (Perrenoud, 1977). Sawai and Waryam (2004) reported that K fertilization reduced the incidence of rice hispa (*Discladispa armigera*) and damage due to grass hopper (*Hieroglyphus banian*).

**Sources:** There are mainly two potassium fertilizers, namely muriate of potash (MOP) (KCl) containing 60% K<sub>2</sub>O and sulphate of potash (SOP) (K<sub>2</sub>SO<sub>4</sub>) containing 48% K<sub>2</sub>O. Due to high cost of SOP mostly MOP is used for rice K fertilization. For rice there is no advantage with sulphate of potash.

**Time and method of application:** Potassium application is mostly recommended at the time of sowing/transplanting. However, split application

**Table 1.17** Rate of decline in grain yield of rice due to NPK fertilization at Faizabad (Uttar Pradesh) over a period of 30 years (1977-2007)

N + P <sub>2</sub> O <sub>5</sub> + K <sub>2</sub> O kg/ha	Yield decline (kg/ha/year)
120 + 0 + 0	108
120 + 0 + 40	89
120 + 80 + 0	51
120 + 80 + 40	39
CD (P=0.05)	18

*Source:* Yadav and Kumar (2009)



of K is recommended in Andhra Pradesh, Kerala, Odisha and Uttar Pradesh (Das *et al.*, 1970; Senthivel and Palaniappan, 1985). Foliar application may be the best way to apply potassium in the flooded rice fields (Thanunathan *et al.*, 2004).

#### General NPK recommendations

Nitrogen recommendations in most states for lowland and irrigated rice vary from 120 to 150 kg N/ha. Only in Kerala the recommendation is slightly less (90 kg N/ha). However, the farmers in less developed and economically poor areas apply lesser than the recommended dose of N, while in Punjab the farmers apply one-and-a-half to two times the recommended dose to rice. Rates of phosphorus applied vary from 30 to 60 kg  $P_2O_5$ /ha, while that of potassium vary from 20 to 60 kg  $K_2O$ /ha. Farmers with lesser resources even skip phosphorus and potassium application and that may partly explain the lower yield obtained by them. Balanced NPK fertilization is a must for high yields. Rates of NPK application for rainfed rice are about 20% lesser than for lowland/irrigated rice. General NPK recommendations for rice vary from 120 to 150 kg N + 30 to 60 kg  $P_2O_5$  + 20 to 40 kg  $K_2O$ /ha in most states of India except the northeastern and part of eastern states, where the recommendation is 80 kg N + 40  $P_2O_5$  + 40 kg  $K_2O$ /ha (NAAS, 2009).

#### Sulphur

About 41% of Indian soils are deficient in sulphur and response of rice to S has been reported from almost all the states (Tandon, 1991; Tewatia *et al.*, 2007). Substitution of high analysis fertilizers such as urea and DAP for ammonium sulphate and single superphosphate has been the main cause for wide-spread S deficiency in Indian soils. The other important factor has been the high harvests of crops resulting in heavy removal of native soil sulphur.

In rice-wheat cropping, Tiwari *et al.* (1997) reported that S application to rice at 40 kg/ha or more increased rice yield significantly and also gave a significant residual effect on the succeeding wheat. The mean grain yield increase (averaged over 8 sites) in rice owing to application of 40 kg/ha was 557 kg/ha and the mean residual effect on succeeding wheat gave an increase in yield of 220 kg/ha. In rice S uptake is reported to be 6.5-15 kg/ha (Tandon, 1991) and 40-50% of it is found in grain. Rice varieties differ in S uptake. Also the crop yield affects S uptake.

Symptoms of S deficiency in plants are similar to that of N, but it can be differentiated on the following points.

- In most crops the younger leaves turn yellow due to S deficiency. In contrast it is the older leaves that turn yellow due to N deficiency.
- S deficiency cannot be corrected even with heavy application of N.
- In S-deficient plants S levels in plant tissue are lower, while N levels are higher.

In rice initially the leaf sheath becomes yellowish and later the leaf blades. At tillering the entire plant appears chlorotic. The panicles are fewer and shorter with lesser spikelets.



**Sources of S:** There are two kinds of S fertilizers. The first kind of fertilizers are the popular ones containing S as the nutrient other than that for which fertilizer is applied. For example, single superphosphate (SSP) is marketed as phosphate fertilizer but contains 12% S. Other examples of such sulphur fertilizers are ammonium sulphate (24% N, 24% S), ammonium sulphate nitrate (26% N, 15% S), ammonium phosphate sulphate (16-20% N, 20% P<sub>2</sub>O<sub>5</sub>, 15% S), potassium sulphate (48% K<sub>2</sub>O, 18% S) and zinc sulphate hepta hydrate (21% Zn, 15% S). The other kind of S fertilizers are those materials which are marketed and used only as a source of S. These include elemental S, gypsum (mostly used for reclaiming sodic soils), iron pyrites and phosphogypsum (a byproduct of phosphoric acid industry). Sulphur in pyrites is present as sulphide and must be oxidized before it becomes available to crop plants. Oxidation of pyrites is faster if it is applied on the surface rather than its incorporation in soil (Sharma and Swaroop, 1997). Sulphur as elemental S has also to be oxidized before it becomes available to crop plants.

Although differences in relative performance of various sources of S have been reported, in general, all sources of S have been found to be equally effective (Tandon, 1991; Biswas and Tewatia, 1991).

**Method of application:** Most S is applied to soil at sowing/final puddling in transplanted rice.

### Micronutrients

So far as rice production in India is concerned, deficiencies of 3 micronutrients have been reported. First of all zinc deficiency in rice fields was noticed in *tarai* soils (Nene, 1966). Later deficiency of Fe was noticed on sandy soils of Punjab (Takkar and Nayyar, 1984). Of late, B deficiency in rice has been reported on highly calcareous soils of Bihar (Sakal *et al.*, 1988). Incidentally all these 3 micronutrients have poor mobility in plants (Prasad and Power, 1997). Data from an analysis of more than 2.52 lakh soil samples from 16 states and two Union Territories for plant available micronutrients are given in Table 1.18.

About 48.8% of the soils were found to be deficient in Zn and the deficiency is prevalent in all states. Iron deficiency was more in Karnataka (35%), Himachal Pradesh (27%), Maharashtra (24%) and Haryana (20%). Boron deficient soils were more in Odisha (69%), Tamil Nadu (68%), Gujarat (57%), Andhra Pradesh (53%) and Madhya Pradesh (49%), although B-deficient crop response is generally reported from the eastern states of Bihar, West Bengal, Asom, Odisha and north-eastern states (Gupta *et al.*, 2007; Behera *et al.*, 2009). Commonly used sources of micronutrients are given in Table 1.19.

**Response to micronutrients: Zinc:** In rice (also in wheat) grown on Zn-deficient soils, brown spots first appear on the young leaves and then spread to lower leaves. These brown spots coalesce and in extreme Zn-deficiency patches of brown burnt plants appear in the field. This Zn deficiency in rice is known as '*Khaira*' [after the dark brown colour of the extract of *Acacia catechu* (*kattha*) used in chewing betel leaves] and was first reported by Nene (1966).



**Table 1.18** Extent of micronutrient deficiency in some states of India

Name of the State/Union Territory	No. of soil samples	Per cent samples deficient (PSD)				No. of soil samples	PDS in HWS-B
		Zn	Cu	Fe	Mn		
Andhra Pradesh	8,158	49.4	< 1	3	1	-	-
Asom	12,165	34.0	< 1	2	20	-	-
Bihar	19,214	54.0	3	6	2	5,270	38
Delhi	201	20.0	-	-	-	-	-
Gujarat	30,152	23.8	4	8	4	2,480	2
Haryana	21,848	60.5	2	20	4	180	0
Himachal Pradesh	155	42.0	0	27	5	-	-
Jammu and Kashmir	93	12.0	-	-	-	-	-
Karnataka	27,860	72.8	5	35	17	21,562	32
Kerala	650	34.0	31	<1	0	-	-
Madhya Pradesh	32,867	43.9	<1	7	1	2,813	22
Maharashtra	515	86.0	0	24	0	-	-
Meghalaya	95	57.0	2	0	23	-	-
Odisha	16,040	54.0	-	0	0	-	-
Puducherry	4,108	8.0	4	2	3	-	-
Punjab	16,483	48.1	1	14	2	263	13
Rajasthan	183	21.0	-	-	-	-	-
Tamil Nadu	28,087	58.4	6	17	6	1,031	21
Uttar Pradesh	26,126	45.7	1	6	3	49	24
West Bengal	6,547	36.0	0	0	3	3,177	68
All India	251,660	48.5	3	12	5	36,825	33

Source: Gupta *et al.* (2007); HWS-B, Hot-water soluble B

**Table 1.19** Common sources of micronutrients

Boron	Borax (11%B), Borate-65(20% B), Boric acid (17% B), Solubor (20% B), Boronated NPK (0.3% B), Colemanite (15% B)
Copper	Copper sulphate (25% Cu), Copper ammonium phosphate (32% Cu), Na <sub>2</sub> CuEDTA (13% Cu), NaCuHEDTA (9% Cu)
Iron	Ferrous sulphate (18-20% Fe), Ferrous ammonium sulphate (14% Fe), Iron pyrites, Iron frits (20-40% Fe), NaFeEDTA 95-14% Fe), Na FeEDDHA (6% Fe), NaFe DTPA (10% Fe)
Manganese	Manganese sulphate (23-28% Mn), Manganese oxide (40% Mn), Manganese frits (10-35% Mn), Na <sub>2</sub> MnEDTA ( 5-12% Mn)
Molybdenum	Sodium molybdate (39% Mo), Ammonium molybdate (54% Mo), Molybdic acid (53% Mo), Fly ash (8-33 mg/kg).
Zinc	Zinc sulphate heptahydrate (21% Zn) (most commonly used zinc fertilizer in India), Zinc sulphate monohydrate (33% Zn), Zinc oxide (80% Zn), Zinc fritz (10-30% Zn), ZnEDTA (12% Zn), Zinc coated or zincated urea (0.5, 1.0, 2.0% Zn)

Rice responds well to Zn fertilization (Prasad, 2006) and the general recommendation is 2 to 10 kg Zn/ha [10 to 50 kg/ha of zinc sulphate heptahydrate (ZSHH)] depending upon Zn-fertility status and soil texture; higher rates are needed on lighter and more Zn-deficient soils. In rice-rice cropping system, Singh and Saha (1997) recommended an application of 5 kg Zn/ha to every third crop or 10 kg/ha to every fourth crop, while in rice-wheat cropping system Zn has to be applied each year preferably to rice. Zinc sulphate heptahydrate (ZSHH) (21% Zn) is the most common zinc fertilizer. A number of other Zn sources are listed in Table 1.19. Some researchers have reported water-soluble Zn fertilizers, such as, ZSHH to be better, while others have not found it to be true. Zn-coated urea (0.5 to 2.0% Zn) could be a useful material, because the farmers will not have to run for zinc fertilizers (Shivay *et al.*, 2008).

**Iron:** Iron deficiency in rice leads to pale green upper leaves, which may bleach in extreme deficiency. Iron deficiency in rice is limited to direct-seeded upland rice, and in dry bed rice nurseries. In nursery beds the iron deficiency can be overcome by flooding the nursery beds. In lowland conditions, the availability of iron increases and may even lead to Fe-toxicity, which is indicated by bronzing of leaves (Dobermann and Fairhurst, 2000). Fe-toxicity is quite frequent in flooded soils of Assam and north-eastern states (Singh *et al.*, 2003). The best way to overcome Fe deficiency in rice is a foliar spray of 0.5% solution of ferrous sulphate. In acute deficiency, more than one sprays may be required. Soil application of iron is no good. Soils already have plenty of Fe and the major problem is its availability.

**Boron:** Boron deficiency develops in apical parts of the plants and is generally associated with the quality of flowers and fruits. Boron is a plant nutrient of great horticultural importance. Response of rice to B application has been reported from Assam, Bihar, Odisha and West Bengal (Shrotriya and Phillips, 2002). Soil application of 1 to 2 kg borax is generally recommended. Higher rates of application may lead to B toxicity. For this purpose, a boronated NPK fertilizer (0.3% B) has been developed (Sarkar *et al.*, 2006). When B deficiency is detected in a late stage of growth of rice a 0.1 to 0.5% boric acid solution may be sprayed on foliage. Boron fertilizers are listed in Table 1.19.

**Remedial measure for micronutrient deficiencies:** Regular application of organic manures can reduce the chances of micronutrient deficiencies. For example, each tonne of farmyard manure (FYM) supplies 1,400 -1,500 g Fe, 142-247 g Zn, 115-220 g Mn, and 8-10 g Cu.

**Sources:** Important source of Zn, Fe and B are listed in Table 1.19. For rice Zn-sulphate and Zn-frits were found to be equally effective in Andhra Pradesh and Madhya Pradesh. In studies carried out in Haryana, Punjab and Madhya Pradesh, ZnO was also found to be as good as Zn-sulphate (Takkur, 1996). Among the iron carriers tested for rice Fe sulphate proved superior to pyrite and biotite (Singh *et al.*, 1978). Addition of FYM or H<sub>2</sub>SO<sub>4</sub> recorded the highest yield and Fe uptake in calcareous Inceptisols, whereas 2.5 tonnes/ha iron pyrite was superior in increasing rice yield in Vertisols (Deore, 1994). In general,



borax and sodium tetraborate are used for soil application, while boric acid is used for foliar spray.

#### **Time and methods of application**

**Zinc:** Soil application of Zn is generally made at sowing/transplanting of rice. In Zn-deficient soils, a significant reduction in rice yield was obtained when Zn application was delayed by 10-20 days (Gupta, 1994). When Zn deficiency is noted in crop, one 0.5% Zn-sulphate spray is generally recommended. However, on Zn-deficient soils, basal application is preferred to foliar application, because in most cases considerable damage is already done before a deficiency is detected. Dipping rice roots in 2-4% ZnO suspension also proved very effective (Takkar *et al.*, 1989).

**Iron:** Fe chlorosis in rice is better controlled by foliar spray of 0.5% Fe-sulphate. Sometimes as many as 6 sprays may be needed (Takkar and Randhawa, 1978). With pyrite or FYM the only choice is soil application at final ploughing/puddling.

**Boron:** Soil application of B should be made when deficiency of B has been established. Indiscriminate use may result in toxicity to plants. When foliar application is must, a 0.2% borax solution (with lime twice the weight of borax) is recommended to avoid injury to foliage.

#### **Integrated nutrient management**

Integrated nutrient management (INM) or integrated plant nutrient supply system (IPNS) refers to the judicious combined use of chemical fertilizers, bio-fertilizers, organic manures, crop residues, and inclusion of legumes for green manuring or grain in the cropping systems (Swarnlakshmi *et al.*, 2006; Prasad, 2008). Legumes grown as green manure, such as, *Sesbania*, or summer mung-bean (*Vigna radiata*) for dual purpose (grain + green manure) can recycle 59 to 143 kg N, 15 to 22 kg P and 25 to 121 kg K/ha/season, while farmyard manure (FYM) can add 4 to 5 kg N, 2 to 2.5 kg P and 5 kg K/tonne (Table 1.20) (Mishra and Prasad, 2000; Sharma and Prasad, 2008).

### **WATER MANAGEMENT**

Rice is the largest consumer of water; about 5,000 litres are required to produce 1 kg rice (IRRI, 1994-95). Water requirement of rice varies from 1,190 to 2,650 ha-mm depending upon soil, climatic conditions and varietal characteristics such as plant type and duration (Table 1.21). Also most irrigated rice is transplanted.

Total water requirement includes water needed to raise seedlings, prepare land and to grow a crop from seedling/transplanting to harvest. The amount is determined by many factors like soil type, topography, proximity to drains, depth of water-table, area of contiguous rice fields, maintenance of bunds, fertility of both top and subsoil, land preparation, duration of crop, and most of all, evaporative demand of the growing season. It may also be mentioned that much of the water applied to rice fields is lost by percolation and surface run off but is included in the water requirement of rice.

**Table 1.20** Integrated effects of organic manures/crop residues and fertilizer N on grain yield of a rice-wheat cropping system (data pooled over 3 years)

Treatment	Manure applied (tonnes/ha)	Amount of NPK added/recycled (kg/ha/year)			Grain yield (tonnes/ha) with different N levels			
		N	P	K	0*	40	80	120
Sesbania GM	5.5	143.0	22.0	121.0	8.1	8.9	9.3	9.3
Cowpea GM	3.5	59.5	15.7	25.2	7.9	8.9	9.2	9.4
Mungbean residue	1.9	28.9	4.0	14.1	8.2	8.5	8.8	9.1
Leucaena	2.0	48.4	5.4	28.0	7.7	8.4	8.9	8.9
Wheat straw	5.0	20.0	0.5	55.0	6.9	7.7	8.3	8.4
FYM	10	42.0	25.0	51.0	7.8	8.6	9.1	9.3
Control	0	0	0	0	6.3	7.1	7.7	8.1

\*Level of N (kg/ha); GM, green manure

Source: Mishra and Prasad (2000)

**Table 1.21** Water requirement of rice in different parts of the country as measured at field head

State/Place	Season	Water requirement (ha-mm)	Reference
<i>West Bengal</i>			
• Kharagpur	<i>Aus</i> (Mar/Apr-Jun/Jul)	1,850	Pande and Mittra (1972)
	<i>Aman</i> (Jul/Aug-Nov/Dec)	1,890	
	<i>Boro</i> (Dec/Jan-Mar/Apr)	2,150	
<i>Odisha</i>			
• Cuttack	<i>Kharif</i> (Jun-Sep)	1,300	Chaudhary and Pande (1968) Pande (1970)
	<i>Boro</i> (Jan-Apr)	1,190	
• Bhubaneswar	<i>Kharif</i> (Jun-Sep)	1,440	Sahu (1967)
	<i>Rabi</i> (Sep-Dec)	1,650	
<i>Uttar Pradesh</i>			
• Roorkee	<i>Kharif</i> (Jun-Oct)	1,620	Gupta and Bhattacharya (1963) Bhattacharya (1972)
• Dhanauri	<i>Kharif</i> (Jun-Oct)	1,630	
<i>Karnataka</i>			
• Siruguppa	<i>Kharif</i> (Jun-Oct)	1,520	Patil (1963)
<i>Tamil Nadu</i>			
• Coimbatore	<i>Samba</i> (Jul/Aug-Dec/Jan)	1,680	Chander Mohan (1967)
• Puttukottai	<i>Samba</i> (Jun-Sep)	2,650	
	<i>Kuruvai</i> (Jun-Sep)	2,000	
<i>Delhi</i>	<i>Kharif</i> (Jun-Oct)	2,400	Hukkeri and Sharma (1974)

Source: Hukkeri and Pande (1977)



### Water need for raising seedlings

It is estimated that 15-20 ha-mm of water is needed for nursery land preparation and 25-40 ha-mm to raise the seedlings for 30-40 days in 0.10 ha area required for planting 1 ha of rice. Thus total water requirement for raising seedlings for 1 ha land is about 40-60 ha-mm.

### Water need for puddling

On an average puddling and transplanting operations in case of lowland rice culture require about 200-300 ha-mm of water/ha (Sharma, 2000).

### Water need for crop growth

The amount of water required depends on the water depth, agronomic practices followed, soil type, evaporative demand and duration of rice variety. In general, water requirement from transplanting to harvest is between 800 and 1,200 ha-mm, which amounts to a daily consumption of 6-10 ha-mm. In addition to the actual crop needs a large amount of water is lost from rice fields. The principal water loss processes from paddy fields are: run-off, percolation, seepage and evapotranspiration or consumptive water use.

In most of the tropics, the evapotranspiration (ET) requirement of rice is about 4-5 mm/day during the wet season and 7-17 mm/day during the dry season for large irrigated areas. For small irrigated areas, the dry season ET may be still higher because of advective energy (energy brought in by wind from drier areas). The ET values of rice determined at a few places are given in Table 1.22.

### Critical growth stages for irrigation

It is generally believed that the peak water demand of rice is between maximum tillering and grain filling; tiller initiation, primordia initiation and flowering are most vital. Number of tillers and panicles/hill and percentage of

**Table 1.22** Evapotranspiration (ET) from rice at different location

Place	Soil type	Season	Seasonal		Daily	
			Absolute (mm)	Percentage	Absolute (mm)	Percentage
Chiplima (Odisha)	Sandy loam	Autumn	426	41.7		
Pantnagar (Uttar Pradesh)	Sandy clay loam	Autumn	653	38.7		
Chala Kudy (Kerala)	Sandy loam	<i>Kharif</i>			4.9	27.5
Kharagpur (West Bengal)	Lateritic	<i>Rabi</i>			5.0	22.5
		<i>Kharif</i>	169	15.3		
Siruguppa (Karnataka)	Clayey	Summer	375	25.2		
		<i>Kharif</i>			7.8	28.3
		Summer			16.8	47.7

Source: Yadav (1972), Rajput (1979, 1981)

filled grains/panicle are sensitive characters (Mane, 1970). Lack of adequate moisture at these stages reduces the yield even up to the extent of 50%.

#### Methods for irrigating rice

Continuous flooding at a static 2-5 cm depth provides an opportunity to produce potential yields. Experiments conducted at various locations in India on lowland rice reveal that the practice of keeping the soil under shallow depth of submergence (2-5 cm) throughout the crop-growth period is conducive to higher yields (Yadav, 1972; Pande and Mitra, 1972; Rajale and Prasad, 1975).

However, for good yields of rice it is not necessary to follow continuous submergence, especially in the *kharif* season when the humidity is high and evaporative demand is low. This is also applicable for shallow water-table conditions. Under these conditions the practice of intermittent submergence, i.e. submergence during the critical stages of initial tillering and flowering and maintenance of saturation or field capacity during the rest of the growth gave yields comparable to those obtained under continuous shallow submergence. The practice of intermittent submergence saves about 30 to 50% water and thus improves water-use efficiency as compared to the continuous submergence. Some data on the water requirement under continuous flooding, alternate wetting and drying, aerobic rice conditions and system for rice intensification are in Table 1.23.

#### Micro-irrigation

Sprinkler irrigation is being used for upland rice in Brazil (Stone *et al.*, 1990). In India, estimated potential for micro-irrigation is at 69.5 million ha (42.5 million ha under sprinkler and 27 million ha under drip) (Modi, 2009), but is mostly targeted for horticultural crops and sugarcane; rice does not figure in these estimates. Srivastava (2009) reported that pipe conveyance resulted in a 36.6% saving in irrigation water in rice. Use of drip irrigation has been successfully attempted in rice in Tamil Nadu and Andhra Pradesh and it brought out a saving of about 33% in irrigation water (Sundip Das, *Financial Express*, 3 July 2010).

#### Drainage

About 6 million ha of rice area is reported to suffer due to waterlogged/flooded conditions in different parts of the the country (CRRI, 1980). At a number of places the problem of excess water is also associated with the salinity and alkalinity problems, which further aggravate the situation.

The extent of drainage and type of drainage system to be adopted will depend on several factors relating to soil, crop, weather and the hydrological characteristics of an area. Moreover, certain stages of growth like flowering have been reported to be more susceptible to waterlogged conditions than other stages of crop growth.

The drainage should be synchronized with the period just following tillering and flowering (Sahu, 1967; CRRI, 1968). The drainage period could last from 3-7 days, depending upon the type of soil. In case of sandy soils drainage period



**Table 1.23** Effect of different water-management practices on the yield (tonnes/ha) of rice at different places

Station	Season	Water-management practice			Reference
		Shallow (5 ± 2 cm) submergence at all stages of crop	Intermittent submer- gence <sup>1</sup>	Saturation at all stages (5 cm submer- gence to field capacity)	
Cuttack (Odisha)	<i>Kharif</i>	5.56	5.83	5.68	Chaudhary and Pande (1968)
	<i>Rabi</i>	5.90	6.03	5.90	
Chakuli (Odisha)	<i>Kharif</i>	3.82	3.65	3.22	Yadav (1972)
	<i>Kharif</i>	3.99	3.82	3.87	Yadav (1973)
Kharagpur (West Bengal)	<i>Kharif</i>	3.96	3.62	3.65	Yadav (1972)
	<i>Rabi</i>	5.18	-	3.38	
Hyderabad (Andhra Pradesh)	<i>Kharif</i>	6.88	6.94	6.57	Yadav (1972)
	<i>Rabi</i>	8.07	6.92	7.01	
Siruguppa (Karnataka)	<i>Kharif</i>	4.99	-	4.91	Yadav (1972)
Delhi	<i>Kharif</i>	4.91	4.92	-	Hukkeri and Sharma (1974)
Hisar (Haryana)	<i>Kharif</i>	3.72	-	3.79	Moolani <i>et al.</i> (1968)
Kanpur (Uttar Pradesh)	<i>Kharif</i>	3.94	3.87	2.82	Singh and Pal (1973)
Tirupati (Andhra Pradesh)	<i>Kharif</i>	6.11	6.63	6.05	APAU (1973- 74)
Bhavanisager (Tamil Nadu)	<i>Kharif</i>	7.96	7.50	6.10	Yadav (1973)

<sup>1</sup>Shallow submergence during initial tillering and/or flowering stage and saturation at other stages

is about 3 days while in the case of clayey soils it is about 5 to 7 days. A study on depth and frequency of drainage conducted at Cuttack (CRRI, 1968) revealed that lowering the water-table up to 30-45 cm below the surface gave the highest yield.

The design of drainage system will also vary with the situation (Sarkar, 1980). However, surface drainage system would be adequate for rice fields as the water-table is not required to be lowered too deep.

### WEED CONTROL

Weeds compete with rice and take away a heavy toll of energy, water and plant nutrients. Weeds are responsible for the drudgery that the farm families suffer in most Asian countries. Weeds are generally more in upland rice than in

lowland and irrigated rice. Weeds deplete considerable amount of nutrients. Mukhopadhaya *et al.* (1972) and Kakati and Mani (1977) reported that weeds divested the rice crops of 24-37 kg N, 5 kg P and 49 kg K/ha. Pillai *et al.* (1976) reported a loss of 93 kg N, 25 kg P and 90 kg K/ha. Similarly, from Bihar a loss of 35 kg N, 4 kg P and 8 kg K, 2.5 kg Fe, 61 g Zn, 15 g Cu and 168 g Mn/ha was reported (Pandey and Thakur, 1988). A brief discussion on the weed species present and their control in rainfed upland, rainfed lowland and irrigated rice follows. For more information, please refer to Pandey (1999) and Das (2008).

#### Rainfed upland rice

Weed problem is most acute in upland rice culture. Many weed species infest rice crop and inflict heavy reduction in crop yield. The most common weed species are:

##### Grasses

*Echinochloa colonum*, *E. crus-galli*, *Eleusine indica*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Paspalum distichum*, *Cynodon dactylon*.

##### Sedges

*Cyperus rotundus*, *Fimbristylis miliacea*.

##### Broad leaf

*Commelina benghalensis*, *Amaranthus spinosus*, *Trianthema portulastrum*, *Eclipta prostrata*; syn. *E. alba*, *Digitaria marginata*, *Ageratum conyzoides*.

##### Control measures

**Manual:** Hand-weeding is the most widely used method for controlling weeds in upland rice. Normally two weedings are done. Time of weeding slightly varies in different regions but weedings are generally done within 15 to 45 days after sowing; this period also coincides with critical period of crop weed competition.

**Mechanical:** Only limited number of implements such as hand-hoes and bullock-drawn *desi* ploughs are used to control weeds in upland direct-seeded rice.

**Chemical:** Commonly used herbicides, their rate and time of application are listed in Table 1.24.

#### Rainfed lowland rice

In lowlying areas, rice is generally direct seeded before the onset or after the onset of monsoon. Initially conditions resemble those of upland direct-seeded rice, but 25 to 35 days after sowing rains come and the conditions change to wetlands. Rainfed lowland rice is also transplanted in certain areas. Generally the yields are low. Poor weed control is an important factor for low yield. A large number of terrestrial, semi-aquatic or aquatic weed species infest the fields depending on the depth of water and other field conditions.



In areas where water level fluctuates up to 25 to 30 cm during crop-growth period, the general composition of weed flora is: grasses 50%, sedges 45% and dicots 5%. In areas where water level rises above 50 cm and may go up to 100 cm or above, aquatic weeds such as *Chara* sp; *Spirogyra* sp., and *Najas* are most common. Dominant weed species in rainfed lowland rice culture are given below.

#### Grasses

*Echinochloa crus-galli*, *E. colonum*, *Paspalum scrobiculatum*, *P. paspaloides*, *Setaria glauca*

#### Sedges

*Scripus* sp., *Cyprus iria*, *C.difformis*, *Elecocharis* sp., *Fimbristylis* sp.

#### Broad leaf

*Monochoria vaginalis*, *Ludwigia octoralis*, *Ipomoea repens*, *Eclipta alba*, *Ammania basifera*, *Nymphaea* sp., *Hydrilla verticillata*, *Potamogeton* sp., *Salvinia* sp.

#### Aquatic weeds

*Chara* sp., *Typha* sp., *Nagas* sp., *Spirogyra* sp., *Marsilia quadrifolia*.

#### Control measures

**Manual:** Hand-weeding is not possible due to stagnation of water in fields during critical period of crop-weed competition.

**Mechanical:** It is the most common method of controlling weeds. A mechanical operation called *beushening* or *biayi* or *bidahan* is widely practiced. It is the practice of cross-ploughing the field having 5 to 10 cm standing water with a *desi* plough a month after sowing once or twice depending upon weed density and rice plant population. The ploughing is followed by laddering the same day or a few days after. This aims at bringing an uniform plant population in the field. This operation results in marked decrease in weed density and increase in rice grain yield (Sahu and Jena, 1968). Nayak and Lanka (1988) also reported that *beushening* followed by two hand-weedings was the best.

**Chemical weed control:** Commonly used herbicides, their rate and time of application are listed in Table 1.24.

#### Transplanted rice

A large number of weed species occur in the transplanted rice fields; the most common are:

#### Grasses

*E. crus-galli*, *E. colonum*, *Digitaria sanguinalis*, *Paspalum distichum*

#### Sedges

*C. rotundus*, *C. iria*, *C. difformis*, *Fimbristylis dichotoma*, *Scirpus* sp.

**Table 1.24** Herbicides recommended, their dosage and time of application for different rice ecosystems

Ecosystem	Herbicide	Dose (g a.i./ha)	Time of application
Upland	Butachlor	1,500	1-2 DAS
	Pendimethalin	1,000	1-2 DAS
	Oxyfluorfen	500	1-2 DAS
	Propanil	2,500	15-20 DAS
	2,4-D sodium salt (for broad leaf)	500	15-20 DAS
Lowland	Butachlor	1,500	1-2 DAS
	Pendimethalin	1,500	1-2 DAS
	Anilofos	400	1-2 DAS
	Propanil	2,000	15-20 DAS
	Fenoxaprop	50	25-30 DAS
	2,4-D sodium salt (for broad leaf)	750	25-30 DAS
Direct-seeded Puddled/non- puddled	Butachlor	1,500	1-2 DAS
	Pendimethalin	1,500	1-2 DAS
	Anilofos	400	1-2 DAS
	Propanil	2,000	15-20 DAS
	Fenoxaprop	50	25-30 DAS
	2,4-D sodium salt (for broad leaf)	750	25-30 DAS
Transplanted	Butachlor	1,000	1-2 DATP
	Pendimethalin	750	1-2 DATP
	Propanil	1,500	15-20 DATP
	Fenoxaprop	50	25-30 DATP
	Ethoxysulfuron	30	15-20 DATP
	Oxadiazyl	70	15-20 DATP
	2,4-D sodium salt (for broad leaf)	750	25-30 DATP

DAS, Days after sowing; DATP, days after transplanting.

For rice nurseries the recommended herbicides are pretilachlor + fenchrom @ 500 g ai/ha 1-2 DAS

Source: Sharma (2007)

### Broad leaf

*Ammania baccifera*, *Eclipta alba*, *Caesulia axillaris*, *Ludwigia parviflora*, *Monochoria vaginalis*.

### Control measures

**Manual:** It is an effective method if hand-weeding is done before critical period of crop-weed competition; it results in marked increase in rice yield.

**Mechanical:** This practice is not in vogue due to closer planting. However, in light-textured soil finger hoe can be used.

**Chemical:** Commonly used herbicides, their rate and time of application are listed in Table 1.24.



### Weed management in rice nursery

Weeds are a major problem in raising healthy nursery. Weed species *E. colonum* and *E. crus-galli* are major weed species that infest the nursery. They are morphologically akin to rice plant and therefore their removal becomes difficult. Further their growth is slow and they do not attain sufficient height within a week. This further compounds the problem of their removal by hand. Pre-emergence application (8 days after sowing) of herbicides like butachlor @ 1 kg/ha, or thiobencarb @ 1 kg/ha, or oxadiazon @ 0.5 kg/ha or pendimethalin @ 1 kg/ha gives excellent control in lowland rice nursery in traditional rice-growing area. In non-traditional rice-growing areas thiobencarb @ 1.5 kg/ha has been found most effective; it gives 79% mortality of weeds (Tiwari *et al.*, 1989).

### PEST MANAGEMENT

Most of the rice pests are distributed throughout India; however, only a few pests are economically important in different regions. The serious pests include gall midge (*Pachydiplosis oryzae*), yellow stem-borer (*Tryporyza incertulas*), green leaf hopper (*Nephotettix nigropictus* or *N. virescens*) and brown planthopper (*Nilaparvata lugens*) in Eastern India; yellow stem-borer, leaf folder (*Cnaphalocrocis medinalis*) and gall midge in western India; yellow stem-borer, brown planthopper, white backed planthopper (*Sogatella furcifera*), leaf folder, gundhi bug (*Leptocoris varicornis*) and climbing cutworm (*Mythimna separata*) in northern India; yellow stem-borer, gall midge, brown planthopper, leaf folder and climbing cutworm in South India; and gall midge, brown planthopper, green leaf hopper and climbing cutworm in central India. The rice case worm (*Nymphula depunctalis*) is prominent in water-stagnating areas, while rice root weevil is problematic in river basins. The rice mealybug (*Ripersia oryzae*), root aphids (*Tetraneura hirsuta*) and termites (*Odontotermes obesus*) inflict serious damage in rainfed areas.

Agronomic practices such as summer ploughing, field sanitation, fertility management, water management, weed management and sowing and harvesting time with slight modifications can be exploited for reducing pest incidence without increasing any extra expenditure. Similarly, mechanical destruction of pests and infested plants or their parts should also be carried out. The preference should be given to the use of resistant cultivars wherever available. The use of selective pesticides including biopesticides should be preferred as they do not disrupt non-target organisms and environment. The economic injury level (EIL) be developed for all the pests. There is need to develop EIL for multipest situations. While determining EIL, the population of natural enemies should also be taken into account. By adopting such measures, the pests in rice ecosystem can be managed in an eco-friendly manner. Pesticides and their doses recommended for control of a few pests are given in Table 1.25.

### DISEASE MANAGEMENT

A number of diseases infect rice crop and some time the effects could be devastating. Important fungal diseases are: rice blast (*Pyricularia oryzae*),

**Table 1.25** Important insect-pests of rice, their nature of damage and chemical control

Pest	Nature of damage	Economic threshold level (ETL)	Chemical control
Brown plant hopper (BPH)	Both nymphs and adults suck sap mainly from basal portion of plants. Damaged plants turn yellow exhibiting 'hopper burn' symptoms. Circular patches of 'hopper burn' are seen in the field under severe infestation. Pest transmits grassy stunt, ragged stunt and wilted stunt diseases.	5-10 hoppers/hill	Apply carbofuran 3 g 20 kg/ha or phorate 10 g 12.5 kg/ha or spray carbaryl 50 wp 0.15% or monocrotophos 36 wsc 0.04% or chlorpyrifos 20 ec 0.05%. Direct the spray towards the base of the plants.
White backed plant hopper (WBPH)	Both nymphs and adults suck sap mainly from the basal portion of the plants. Attacked plants turn yellow and rust red from tip downwards exhibiting 'hopper burn' symptoms.	5-10 hoppers/hill	Apply carbofuran 3 g 20 kg/ha or phorate 10 g 12.5 kg/ha or spray carbaryl 50 wp 0.15% or monocrotophos 36 wsc 0.04% or chlorpyrifos 20 ec 0.05%. Direct the spray towards the base of the plants.
Green leaf hopper (GLH)	Both nymphs and adults suck sap from foliage. The infested leaves turn brown from tip downwards exhibiting 'hopper burn' symptoms. The pest transmits tungro virus disease.	2 hoppers/hill in tungro endemic areas	Apply carbofuran 3 g 20 kg/ha or phorate 10 g 12.5 kg/ha or spray carbaryl 50 wp 0.15% or monocrotophos 36 wsc 0.04% or chlorpyrifos 20 ec 0.05%.
Rice mealy bug	Both nymphs and adults suck sap from stems of plants. Plants remain stunted and even dry under high incidence. The infestation is localized in patches.	NA*	Spray fenitrothion 50 ec 0.1% or dimethoate 30 ec 0.03% or malathion 50 ec 0.1%. Direct the spray towards the base base of plants.
Paddy aphid	Both adults and nymphs suck sap from foliage and panicles and cause yellowing of leaves. Severe infestation results in chaffy earheads.	NA*	Spray fenitrothion 50 ec 0.1% or dimethoate 30 ec 0.03% or monocrotophos 36 wsc 0.04%.
Yellow stem-borer	Caterpillars enter the tiller to feed and cut the central shoot at the base producing 'dead harts' in	5% dead hearts during vegetative stage, 2%	Adopt seedling root dip treatment in 0.05% chlorpyrifos emulsion for one minute before transplan-

Table 1.25 contd



Table 1.25 contd

Pest	Nature of damage	Economic threshold level (ETL)	Chemical control
	young plants. After panicle initiation the damage by caterpillars results in chaffy panicles called 'white ears'.	white ears during panicle stage	ting in endemic areas. Apply carbofuran 3 g or 20 kg/ha or phorate 10 g or 12.5 kg/ha or spray malathion 50 ec 0.1% or phosalone 35 ec 0.1% or quinalphos 25 ec 0.04% or fenitrothion 50 ec 0.1%. Spray should coincide with hatching of borer eggs.
Leaf folder	Larvae fold the leaves by fastening leaf margins with stitches and then feed on green tissue inside the fold. The infested leaves become white and membranous.	4% folded leaves	Spray carbaryl 50 wp 0.25% or quinalphos 25 ec 0.05% or monocrotophos 36 wsc 0.04% or chlorpyrifos 20 ec 0.05% or fenitrothion 50 ec 0.06%.
Climbing cutworm	Young larvae feed on foliage. Mature larvae climb the plants and cut off the earheads or their rachies during night. During day larvae hide at the base of plants. Panicles and grains are seen lying in the field.	4-5 larvae/m	Dust malathion or carbaryl 25-30 kg/ha or spray chlorpyrifos 20 ec 0.05% or quinalphos 25 ec 0.075%. Direct the spray towards the base of the plants.
Swarming caterpillar	Larvae damage the crop both in nursery and field. They feed voraciously and leave behind only the stalks of the plants. The crop looks as if grazed by cattle. The caterpillars migrate in large numbers from field.	NA*	Dust carbaryl or malathion 25-30 kg/ha or spray chlorpyrifos 20 ec 0.05% or quinalphos 25 ec 0.075%. Direct the spray towards the base of the plants and soil crevices. Carry out control measures on community level.
Green horned	Larvae defoliate the plants by either completely eating the leaves or the mid-rib after eating the leaf lamina. Damaged crop presents grazed look.	NA*	Dust carbaryl or malathion 25-30%w/ha or spray chlorpyrifos 20 ec 0.05% or quinalphos 25 ec 0.075%
Rice caseworm	Young larvae feed on green tissues of the leaf. Mature larvae cut leaf tips and roll them to form tubular cases in which they live. Larvae feed during night by protruding	NA*	Spray monocrotophos 36 wsc 0.04% or carbaryl 50 wp 0.25%.

Table 1.25 contd

Table 1.25 *concluded*

Pest	Nature of damage	Economic threshold level (ETL)	Chemical control
	their heads from the cases. Cases can be seen attached to plants at water level or floating in water.		
Rice hispa	Both grubs and adults damage the crop in nursery as well as field. Grubs feed by mining into the leaves. Beetles feed on chlorophyll between the veins of the leaf lamina producing parallel white streaks.	2 adults or 2 damaged leaves/hill	Dust carbaryl or malathion dust 25-30 kg/ha or spray chlorpyrifos 20 EC 0.05% or quinalphos 25 EC 0.075% or monocrotophos 36 wsc 0.04%.
Rice root weevil	Grubs feed on roots of the plants. Infested plants appear stunted, yellowish and lodge. Translucent white grubs are found clinging to the roots of the plants.	NA*	Apply carbofuran 3 g 20 kg/ha or phorate 10 g 12.5 kg/ha.
Gall midge	Maggots enter the stem and feed on growing point of the central shoot. As a result of feeding the central leaf of the attacked tiller is converted into shining tubular structure called 'silver shoot'. The affected tiller does not produce any panicle.	5% silver shoots	Carryout seedling root dip treatment in 0.05% chlorpyrifos emulsion for one minute before transplanting in endemic areas. Apply carbofuran 3 g 20 kg/ha or Phorate 10 g 12.5 kg/ha or spray carbaryl 50 WP 0.15% or monocrotophos 36 wsc 0.04% or phosalone 35 EC 0.1% or fenitrothion 50 EC 0.1%.
Rice gundhi bug	Both nymphs and adults suck juice from developing grains during milky stage and as a result some of the grains in the panicle remain chaffy. Black or brown spots appear around the puncture made by bugs in the grain.	1 bug/hill	Dust carbaryl or malathion 25-30 kg/ha or spray malathion 50 EC 0.1% or fenitrothion 50 EC 0.1% in early morning or late evening.
Panicle thrips	Both nymphs and adults damage the crop by desapping emerging panicles which results in chaffy grains. In severe infestation entire panicle may remain chaffy	NA*	Spray malathion 50 EC 0.1% or carbaryl 50 WP 0.1% or monocrotophos 36 wsc 0.04% or dust malathion or carbaryl 25-30 kg/ha.

Source: Subhash Chander (1999)



sheath blight (*Rhizoctonia solani*), bakanae disease (*Fusarium moniliforme*) and false smut (*Ustilaginoides virens*). The most important bacterial disease is bacterial leaf blight (*Xanthomonas oryzae*). A number of viruses also attack rice crop; the most important being tungro and grassy stunt. In addition, rice stem nematode (*Ditylenchus angustus*) causes ufra disease, while white tip nematode (*Aphelenchoides besseyi*) also infects rice crop.

The best way to overcome disease problem is to use disease-free seed. For fungal and bacterial diseases seed should be treated with ceresan @ 2 g/kg seed. For nematodes the seed treatment involves hot water treatment at 55°C for 10-15 minutes. When a disease is noticed in the field, infected plants should be uprooted and burned. Fungicides such as zineb, hinosan etc. can be sprayed to control a disease. Some rice diseases, their symptoms and management are given in Table 1.26.

**Table 1.26** Important diseases of rice, their symptoms and integrated management

Disease name and causal organism	Symptoms	Integrated management
Leaf and neck blast ( <i>Pycularia grisea</i> : fungal disease)	<p>Infects at an growth stage of rice-seedlings or plants at the tillering stage are often completely killed when leaves are severely infected. All above-ground parts of the rice plant are attacked by the fungus. Initial symptoms on the leaves are white to grayish green circular lesions or spots with dark green borders. Older lesions on the leaves are elliptical or spindle-shaped and whitish to gray with brownish or necrotic border. Later on, lesions on the leaves may enlarge and coalesce to kill the entire leaf. Lesions on the neck are grayish brown and cause the girdling of the neck and the panicle to fall over. If infection of the neck occurs before milk stage, no grain is formed, but if infection occurs later, grains of poor quality are formed.</p>	<p>Cultural practices include early sowing of seeds after the onset of the rainy season and balanced use of fertilizers. Soils known to be low in plant-available silicon should be amended with calcium silicate slag. Planting resistant varieties against the rice blast is the most practical and economical way of controlling rice blast. Systemic fungicides, such as probenazole, tricyclazole, fthalide, pyroquilon and tricyclazole, are effective against the disease.</p>
Bacterial leaf blight ( <i>Xanthomonas oryzae</i> pv. <i>oryzae</i> )	<p>Symptoms include water-soaked to yellowish stripes on leaf blades starting at leaf tips. Lesions turn yellow to white as the disease advances.</p>	<p>Preventive measures include field sanitation such as removing weed hosts, rice straws, ratoons, and volunteer seedlings. Likewise, maintaining</p>

Table 1.26 contd

Table 1.26 contd

Disease name and causal organism	Symptoms	Integrated management
	<p>Appearance of bacterial ooze that looks like a milky or opaque dewdrop on young lesions early in the morning is an important symptom. Leaves wilt and roll up and become grayish green to yellow and finally entire plant wilt completely.</p>	<p>shallow water in nursery beds, providing good drainage during severe flooding, ploughing under rice stubble and straw following harvest are also management practices that can be followed. The use of resistant varieties is the most effective and the most common management practice. Seed treatment with bleaching powder (100 µg/ml) and zinc sulphate (2%) reduces the incidence of bacterial blight. Spraying with copper fungicides alternatively with streptomycin (250 ppm) is effective in controlling bacterial blight. Varieties like TKM 6 and IR 42 and Chinsurah Boro II are tolerant to disease.</p>
<p><b>Bakanae</b> (<i>Gibberella fujikuroi</i> : fungal disease)</p>	<p>Bakanae is primarily a seed-borne disease. Sowing ungerminated seeds in infested soil gives rise to infected seedlings. Infection usually occurs during seedling and tillering stages. Infected plants are several inches taller than normal plants in seedbed and field. Thin plants with yellowish green leaves and pale green flag leaves. Dying seedlings at early tillering. Reduced tillering and drying leaves at late infection. Partially filled grains, sterile, or empty grains for surviving plant at maturity. In the seedbed, infected seedlings with lesions on roots die which may die before or after transplanting.</p>	<p>Clean seeds should be used to minimize the occurrence of the disease. Salt water can be used to separate lightweight, infected seeds from seed lots. Seed treatment using fungicides such as thiram, thiophanate-methyl, or benomyl is effective before planting. Benomyl at 1-2% of seed weight should be used for dry seed coating. However, rapid development of resistance against benomyl and carben-dazim have been observed which may be caused by successive applications as a seed disinfectant. Triflumizole, propiconazole and prochloraz were found to be effective against strains that are resistant to benomyl and combination of thiram and benomyl.</p>
<p><b>False smut</b> (<i>Ustilagoidea virens</i>: fungal)</p>	<p>There are two types of infections. One occurs at flowering stage when the</p>	<p>Resistant or tolerant varieties should be grown. Among the cultural control, destruction of</p>

Table 1.26 contd



Table 1.26 contd

Disease name and causal organism	Symptoms	Integrated management
disease)	ovary is destroyed but the style, stigmas, and anther lobes remain intact and are buried in the spore mass. The second infection occurs when the grain is already mature. The spores accumulate in the glumes. The spores absorb moisture, swell, and force the lemma and palea to open. The fungus contacts the endosperm and growth is observed. The whole grain is replaced with a mass of spores (Mature spores are orange and turn yellowish green or greenish black).	straw and stubble from infected plants is recommended to reduce the disease. In areas where the disease may cause yield loss, applying captan, captafol, fentin hydroxide, and mancozeb can inhibit conidial germination. At tillering and preflowering stages, spraying of carbendazim fungicide and copper base fungicide can effectively control the disease.
Bacterial leaf streak ( <i>Xanthomonas oryzae</i> pv. <i>oryzicola</i> )	The disease is usually observed during the tillering stage of the rice crop. Older plants are more resistant to the disease. The disease is transmitted through seeds to the next planting season. Planting of infected seeds, which are collected from diseased fields produce diseased seedlings. Bacterial leaf streak can be distinguished from bacterial blight by its thinner translucent lesions with the yellow bacterial ooze. Initially, small, dark-green and water-soaked streaks on interveins from tillering to booting stage occur. Streaks are dark green at first and later enlarge to become yellowish-gray and translucent. Lesions turn brown to grayish-white then dry when disease is severe.	The disease can be controlled by proper application of fertilizers and proper plant spacing, the use of resistant varieties, and hot water treated seeds. Practicing field sanitation is important. Providing good drainage system especially in seedbeds can also manage this disease. Fallow field and allowing to dry thoroughly is also recommended.
Stem rot ( <i>Sclerotium oryzae</i> ; fungal disease)	Blackish, dark, irregular lesions are visible on the outer leaf sheath. The lesion later expands and affects the inner culm. If infected culm is dissected, it reveals dark gray	Cultural measures include burning straw and stubble or any crop residue after harvest or letting the straw decompose and draining the field can reduce sclerotia in the field. A

Table 1.26 contd

Table 1.26 contd

Disease name and causal organism	Symptoms	Integrated management
Sheath blight ( <i>Rhizoctonia solani</i> ; fungal disease)	masses of fungi and small white and black sclerotia or infection bodies. Infected stem rots. Infected culm lodges and caused unfilled panicles and chalky grain. Severe infection causes tiller death. As the disease aggravates the plants lodge.	balanced use of fertilizer or split application with high potash and lime to increase soil pH reduces stem rot infection and increases yield. The use of resistant cultivars may be the best control measure for stem rot. Chemicals such as fentin hydroxide sprayed at the mid-tillering stage, thiophanate-methyl sprayed at the time of disease initiation can reduce stem rot incidence in the rice field.
Tungro virus	The disease is soil-borne. It usually starts at the base of the plant near the water level. Later, the symptoms are observed on the upper leaf sheath and on the leaf blade. The disease usually infects the plant at late tillering or early internode elongation growth stages. Initial lesions are water-soaked to greenish gray and later becomes grayish white with brown margin. Lesions may coalesce to form bigger lesions, and eventually death of the whole leaf. Filled or empty grains, especially those on the lower portion of the panicles.	Seeding rate or plant spacing should be optimized to avoid closer plant spacing or dense crop growth. Need-based or real-time application of nitrogen fertilizer. Sanitation, specifically removing of weeds, can help control sheath blight. Removal of infected stubbles or crop residues from the field. Spraying infected plants with fungicides, such as benomyl and iprodione, and antibiotics, such as validamycin and polyoxin, is effective against the disease.
	Tungro virus disease is transmitted by leafhoppers, wherein the most efficient vector is the green leaf hopper. Tungro virus disease affects all growth stages of the rice plant specifically the vegetative stage. Leaf discolouration begins from leaf tip and extends down to the blade or the lower leaf portion. Infected leaves may also show mottled or striped appearance—stunting. Other symptoms are reduced tillering; delayed flowering,	Planting of resistant varieties against tungro virus disease is the most economical means of managing the disease. Observing a fallow period of at least a month to eliminate hosts and viruses and vectors of the disease and ploughing and harrowing the field to destroy stubbles right after harvest in order to eradicate other tungro hosts are also advisable.

Table 1.26 contd



Table 1.26 concluded

Disease name and causal organism	Symptoms	Integrated management
<i>Khaira</i> disease (physiological disorder)	<p>which may delay maturity; panicles small and not completely exerted; most panicles are sterile or partially filled grains and covered with dark brown blotches.</p> <p>It is caused by the zinc deficiency. Symptoms appear between two and four weeks after transplanting, with uneven plant growth and patches of poorly established hills in the field, but the crop may recover without intervention. Under severe Zn deficiency, tillering decreases and can stop completely and time to crop maturity increases. Zn deficiency can also increase spikelet sterility in rice. Midribs, particularly near the leaf base of younger leaves, become chlorotic and leaves lose turgor and turn brown as brown blotches and streaks appear on lower leaves, enlarge, and coalesce. A white line sometimes appears along the leaf midrib. Plant growth is stunted and leaf blade size is reduced.</p>	<p>Soil application of zinc sulphate heptahydrate @ 20-25 kg/ha before sowing/transplanting. If Zn-deficiency symptoms are observed in the field, immediately apply 20-25 kg/ha <math>ZnSO_4 \cdot 7H_2O</math>. Apply 0.5-1.5 kg Zn/ha as a foliar spray (e.g. a 0.5% <math>ZnSO_4</math> solution at about 200 litres water/ha) for emergency treatment of Zn deficiency in growing plants. Start at tillering (25-30 DAT), two or three repeated applications at intervals of 10-14 days may be necessary. Zn chelates (e.g. Zn-EDTA) can be used for foliar application, but the cost is greater.</p>

Source: Rice Knowledge Bank 2006 [www.irri.org](http://www.irri.org)

### CROPPING SYSTEMS

Rice-wheat system covering about 10 million ha in the Indo-Gangetic Plains and about 3 million ha in other parts of the country is the largest cropping system in India (Prasad, 2005). This is followed by rice-rice cropping system. Other rice-based cropping systems in different agro-climatic regions of the country are given in Table 1.27. It may be mentioned that there are still large areas under rice-fallows in the country, where a second crop can be successfully grown, with some life-saving irrigation. Micro-irrigation has a great role to play in growing a second crop after rice.

### POST-HARVEST CARE, STORAGE AND PROCESSING

Paddy is generally harvested at about 20-26% moisture content (wet basis) and has to be dried to about 16-22% moisture before threshing. Although

**Table 1.27** Rice-based cropping systems in different agro-climatic regions of India

Agroclimatic region (No.)	Rainfall (mm)	Soils	Predominant cropping system
Western Himalayan (1) (HP, J&K, UT)	1,650-2,000	Hill and Sub-montane	Rice-wheat, Rice-potato-potato
Eastern Himalayan (2) (Asom, NE states, WB)	1,840-3,528	Red sandy, Laterite, hill, Alluvial	Rice-fallow, Rice-rice Rice-pulses/oilseeds
Lower Gangetic Plain (3) (WB)	1,302-1,607	Alluvial, Red and yellow	Rice-rice, Rice-wheat Rice-potato- jute/veg.
Middle Gangetic Plain (4) (Bihar, eastern UP)	1,211-1,470	Alluvial, <i>Tarai</i> and Calcareous	Rice-wheat Rice-maize, Rice-potato-sunflower
Upper Gangetic Plain (5) (central and western UP)	721-979	Alluvial, <i>Tarai</i>	Rice-wheat Sugarcane-ratoon- wheat
Trans. Gangetic Plain (6)	360-890	Alluvial and Calcareous	Rice-wheat
Eastern Plateau and Hills (7) (CHH, JH, MP, MA)	1,296-1,436	Red, Yellow Laterite	Rice-blackgram Rice-niger/linseed Rice-vegetables
East coast Plain and Hills (11) (AP, OR, TN, PU)	780-1,287	Deltaic alluvium, Red, Laterite	Rice-groundnut- greengram, Rice- greengram/ Blackgram, Rice-rice
West coast Plains and Hills (12) (Goa, MA, KA, KE, TN)	2,226-3,640	Coastal alluvium, Red, Laterite	Rice-rice
Andaman and Nicobar Island (15)	1,600-3,000	Red	Rice-fallow

AP, Andhra Pradesh; CHH, Chhattisgarh; JH, Jharkhand; KA, Karnataka; KE, Kerala, MP, Madhya Pradesh; MA, Maharashtra; OR, Odisha; PU, Puducherry; TN, Tamil Nadu; UP, Uttar Pradesh; UT, Uttarakhand

Numbers in parentheses are the numbers allotted to different agroclimatic regions by the Planning Commission.

Source: Gill *et al.* (2008)

mechanical driers are available and used, most paddy is dried by spreading it in the sun. It dries during the day but again absorbs some moisture during the night. Thus it undergoes several cycles of drying and wetting, which cause fine cracks in the grain. These cracks are known as sun-cracks and are responsible for break-ups during milling.

### Storage

Paddy should be stored in good air-tight container, which should protect it against humidity, moisture, insects-pests, rodents, microorganisms (which thrive in humid environment) and other contaminants.



### **Milling**

Rice has to be milled before consumption. Rice millers range from home scale to large-scale commercial scale; the ones with miller roll sheller are the best and result in least breakage of grains. Various operations in a rice mill are cleaning, de-husking, husk separation, paddy separation (brown rice), polishing (removal of aleurone layer from brown rice to produce white rice) and grading (separation of white rice from brown rice). For more details on the kind of hullers, polishers etc, please read Singh (1999).

The percentage of white rice grain obtained in paddy after milling (head recovery) is about 66% (about two-thirds of weight of paddy) and varies due to variety, drying process, storage and kind of huller and plusher.

### **Parboiling**

This is a hydrothermal treatment given to paddy for improving its milling quality and nutritive value. In this rice is soaked in water, steamed and dried. Parboiling improves head recovery and vitamins and micronutrients in rice. Head recovery is improved because sun-cracks are partly taken care of. As regards vitamins and micronutrients, these are generally present in the aleurone layer of the rice kernel and move in the grain on parboiling.

## **BY-PRODUCTS OF RICE MILLING**

### **Husk**

It is used as domestic and commercial fuel. It has about 20% ash, 90% of which is silica. It is used for making sodium silicate, silica gel and charcoal.

### **Bran**

It is aleurone layer separated from brown rice. It contains 12-15% protein, 14-25% oil and is rich in vitamin B-complex. Rice bran is used for oil extraction. It is also used as animal feed.

### **Broken rice**

Broken rice can be made into flour and used for making many rice dishes. It is also used as poultry feed.

## **SUMMARY**

- Rice is a plant of Asian origin and 90% of the world's rice is produced and consumed in Asia. India the country having the largest area in the world has only 40.5% of the productivity reached in USA and 48.5% of that in China. A large number of factors such as drought, lodging, weeds, soil acidity/sodicity/poor fertility, insect-pests, diseases and rodents are responsible for low yields in India. There are 6 major rice ecosystems, namely irrigated wet season (*kharif*), irrigated dry season (*rabi*), rainfed lowland, rainfed upland deep water regions and coastal lowland.
- Most rice is grown on soils, belonging to the orders: Aquepts, Aquepts, Orchepts, Tropepts, Aqualfs and Aquults. As regards texture, rice is grown on loamy sands in Punjab to clay loams and clays in Andhra Pradesh and



several other states. One important characteristic of rice soils is that they remain submerged at least for some time during the growing period of rice crop. Submergence leads to (i) increase in pH in acid soils and decrease in pH in sodic soils, thus tending to reach near neutral pH; (ii) reduced redox potential; (iii) reduction of nitrate to  $N_2O$  or  $N_2$ , sulphate to sulphide, manganic to manganous and ferric to ferrous, and (iv) increased availability of native soil P due to release of occluded P.

- Twentytwo species of genus *Oryza* ( $2n=24$ ) are recognized, of which only two species, namely *O. sativa* and *O. glaberrima*, are cultivated. *O. glaberrima* is cultivated only in Africa, where also *O. sativa* is gradually taking over owing to high yield potential and wider adaptability. Cultivated varieties of *O. sativa* are grouped into 3 ecotypes, namely *indica*, *japonica* (grown in Japan) and *javanica* (grown in Indonesia). In recent years, a number of high-yielding varieties of rice have been developed. Also a number of rice hybrids have been developed.
- There has also been some emphasis on research for better grain quality. Medium slender medium bold grains without belly are preferred. Aroma and fluffiness on cooking are other desirable traits. Pusa 1121 is an example of fine grain scented yet high-yielding rice variety with a potential of 5 tonnes/ha.
- Adequate supply of essential plant nutrients is a must for getting good rice yields. Rice needs balanced NPK fertilization and responds well to Zn application. Fe and B deficiencies are localized and their application is necessary only in those regions. Management of nitrogen in rice is difficult due to a number of N loss mechanisms, namely surface run-off, ammonia volatilization, leaching and denitrification. Split application, placement or incorporation of N, use of neem cake (or other neem products)- coated urea and use of urea supergranules are some ways to reduce these losses. Zinc deficiency in rice is known as *khaira* disease characterized by browning of leaves or burnt look of rice plants.
- Although thin (2-5 cm) continuous submergence up to the grain-filling stage gives the highest yields, considerable water saving without much loss in rice yield is possible by intermittent submergence, i.e. applying 2-5 cm deep irrigation when the moisture in the field dries out but before the cracks develop. Much of the water applied to rice fields is lost by run-off, percolation and seepage. Efforts should be made to reduce water losses. Consumptive use of water (water lost by transpiration and evaporation) varies from 169 to 653 mm. Of the cereal crops, rice consumes the largest amount of water; about 3,000 litres or more water may be needed to produce 1 kg rice.
- Weeds are a menace in rice crop, more so in direct-seeded rainfed upland rice. Two to three hand-weedings are needed. A number of herbicides are now available, the most commonly used are 2,4-D, butachlor, pendimethalin, oxadiazon and benthocarb.
- There are a large number of insect-pests that attack rice crop. Some important ones are gall midge, brown planthopper, yellow stem-borer, green



leaf hopper, gundhi bug and climbing cutworm. Agronomic practices such as summer ploughing, field sanitation, soil fertility, water and weed management and harvesting time with slight modification can be exploited for reducing pest incidence without increasing expenditure. A number of insecticides are available for effective control of insect-pests. Important diseases of rice are blast, brown leaf spot, sheath blight, Bakanae disease, false smut, bacterial leaf blight. In addition, Tungro and grassy stunt viruses and some nematodes also infect rice crop. Use of disease-resistant variety is the best way to overcome the disease problem. Seed treatment with cerasan or bavistin and hot water treatment for virus control are also effective. For immediate control after an infection is noted, fungicides such as Zineb, Hinosan etc. can be used.

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## Wheat

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DeCandolle believed that wheat originated in the Valley of Euphrates and Tigris and spread from there to China, Egypt and other parts of the world. Vavilov (1950) after extensive studies of the origin of cultivated plants, came to the conclusion that the origin of the durum wheat (*Triticum durum* Desf.) was probably in the region of Abyssinia, whereas the whole group of soft wheats (*Triticum* sp.) probably originated in the region of Western Pakistan, South-Western Afghanistan and the southern parts of mountainous Babshara. Records from ancient China show that it was cultivated there by 2700 BC, and it was known also to the Egyptians and to inhabitants of Switzerland as early as the Stone Age. In India, evidences from Mohen-Jo-Daro excavations, indicate that wheat was cultivated here more than 5000 years ago.

### SPREAD AND COVERAGE

Wheat (*Triticum aestivum* L. emend. Fiori & Paol.) is number one cereal of the world and is grown on the largest area. As a contrast to rice, wheat is grown in all the continents of the world. The global area under wheat in 2009 was 226 million ha as compared to 158 million ha under rice (Table 2.1). As regards global production, it is next only to maize; in 2009, 686 million tonnes wheat was produced as compared to 819 million tonnes of maize and 685 million tonnes of paddy or unhulled rice. The highest per hectare yield of 7.9 tonnes/ha in 2009 was obtained in UK, followed by 7.8 tonnes/ha in Germany, 7.5 tonnes/ha in France and 4.7 tonnes/ha in China. In India the average yield of wheat in 2009 was only 2.9 tonnes/ha; it was almost the same in USA.

In India, a major breakthrough in wheat production started in 1967/1968 with the introduction of dwarf Mexican wheats, when the production increased by more than one- and- a half time, from 10.4 million tonnes in 1964-65 to 16.5 million tonnes in 1967-68. A study of annual growth rates for area, production and yield per hectare shows that the rate of increase in area under wheat was the highest during 1950's and the least during 1980's. The average increase in the growth rate of area under wheat during 1950-2003 was 2% (Kumar *et al.*, 2007) (Table 2.2). However, the growth rate of production of wheat was the highest during 1960's, mainly owing to the introduction of high-yielding dwarf Mexican wheats that led to the Green Revolution or rather Wheat Revolution.



**Table 2.1** Area, production and yield of wheat in some major wheat-growing countries in 2009

Continent/country	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)
<i>Asia</i>			
India	27.8	80.7	2.9
China	24.3	115.1	4.7
Pakistan	9.0	24.0	2.7
Turkey	8.0	20.6	2.6
<i>Africa</i>			
Egypt	1.3	8.5	6.4
<i>Europe</i>			
France	5.1	38.3	7.4
UK	1.8	14.4	7.9
<i>North America</i>			
Canada	9.6	26.8	2.8
USA	20.2	60.3	3.0
<i>South America</i>			
Argentina	4.3	7.5	1.7
<i>Oceania</i>			
Australia	13.5	21.7	1.6
World total	225.6	685.6	3.0

Source: FAO and Directorate of Economics and Statistics, DOAC, Ministry of Agriculture, India (2011)

This is also true for the growth rate in yield/ha. The average growth rate in the production and yield/ha during 1950-2003 was 5.09 and 3.09 respectively. This was owing to continuous increase in area under high-yielding varieties, which increased from 35.3% of the total wheat area in 1970-71 to 90.2% in 2000-01. Also the wheat area under irrigation increased from 34.0% in 1950-50 to 87.2% in 2000-01 and the fertilizer consumption increased from 55 thousand tonnes in 1950-51 to 28.1 million tonnes in 2010-11.

The wheat researchers in India have divided country's wheat area under 6 zones, namely north hill zone, north-western plains zone, north-eastern plains zone, central zone, peninsular zone and south hill zone (Tandon and Sethi,

**Table 2.2** Growth performance of wheat in India (annual growth rate %)

Period	Area	Production	Yield/ha
1950s	3.97	5.04	1.08
1960s	2.23	6.59	4.36
1970s	2.37	4.22	1.85
1980s	0.45	3.51	3.06
1990s	1.70	3.51	1.80
1990-2003	2.00	5.09	3.09

Source: Kumar *et al.* (2007)

1987). Most zones cultivate *T. aestivum*; *T. durum* is preferred in Central Zone. Description of these zones is given below.

#### **Northern hill zone (NHZ)**

Foot-hills of Himalayas in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh form this region. Nearly 4% of area and 3% of wheat production in India is contributed by this zone. Crop durations are long, starting from October/November, they end in May/June. On higher hills the crop is sown in May-June and harvested in October-November. *T. aestivum* is grown in this zone.

#### **North-western plains zone (NWPZ)**

This zone covers arid western plains and includes Punjab, Haryana, Delhi, Rajasthan and Western Uttar Pradesh and covers nearly 37% of area and contributes about 45% in total wheat production of the country. Wheat is sown in mid-November and harvested in April/May. *T. aestivum* is grown in this zone.

#### **North-eastern plains zone (NEPZ)**

This zone comprises eastern Uttar Pradesh, Bihar and West Bengal and contributes about 24% of total production of wheat from 27% area. Crop season spans from November till March/April. Winters are relatively short in this zone. Sowing is often delayed due to higher moisture conditions in the fields after rice. *T. aestivum* is grown in this zone.

#### **Central zone (CZ)**

Parts of arid western India, Central India and Vindhyas comprise this zone. This zone covers nearly 17% area and contributes 13% in production. Crop is sown during October and harvested by March. *Triticum durum* is preferred in this zone.

#### **Peninsular zone (PZ)**

The Deccan plateau, Western Ghats and Karnataka plateau comprise this zone. This zone has 6% area and contributes 2.5% in total production of wheat. The crop is sown during later half of October and harvested by March. *T. aestivum*, *T. durum* and *T. diococcum* Schubl. are cultivated in this zone. Thermo-insensitive varieties are most preferred.

#### **Southern hill zone (SHZ)**

The zone comprises hilly areas of Tamil Nadu and Kerala. Wheat has a minor importance with respect of area and production. Though *T. aestivum* is the predominant species, *T. diococcum* is also grown in some areas. Wheat is grown twice a year in this zone, i.e. May to September and October to April. Stem rust perpetuates in this zone.

Potential and actual yields (on-farm trials) and the yield gaps in different wheat zones are given in Table 2.3. In the Indo-Gangetic Plain (IGP), the major wheat-growing region of the country, the yields are the highest in Punjab (NWPZ) and decline by about 100 kg/ha for every 100 km as one moves



eastward from Amritsar in Punjab to Jalpaiguri in West Bengal in NEPZ (Nagarajan, 2005). This is mainly due to the fact that temperature trajectory of the wheat-growing season affects the grain yield. As one moves eastward in IGP the winters get shorter as the warming starts right from February in West Bengal as compared to April/May in Punjab and Himachal Pradesh.

**Table 2.3** Potential and actual yields and yield gaps in different wheat zones

Zone	Potential yield (tonnes/ha)	Actual yield (tonnes/ha)	Yield gap	
			(tonnes/ha)	(%)
NHZ	2.66	1.7	0.96	56.9
NEPZ	3.73	2.71	1.02	37.6
NWPZ	4.80	3.96	0.84	21.2
CZ	3.45	2.58	0.87	23.6
PZ	3.38	2.77	0.61	22.2
SHZ	2.57	1.20	1.37	14.0

Source: Singh *et al.* (2007)

Among the different states of India, Uttar Pradesh ranks first in area and total production (Table 2.4), while Punjab ranks first in yield/ha. The major factors responsible for higher productivity in Punjab are low temperatures prevailing over a long period providing a longer duration for wheat growth, assured irrigation and adequate fertilization.

**Table 2.4** Area, production and productivity of wheat in major wheat-growing states of India in 2009-10

State	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)
Asom	0.06	0.06	1.09
Bihar	2.19	4.57	2.08
Gujarat	0.88	2.35	2.68
Haryana	2.49	10.50	4.21
Himachal Pradesh	0.35	0.33	0.93
Jammu and Kashmir	0.29	0.29	1.00
Jharkhand	0.10	0.17	1.74
Karnataka	0.28	0.25	0.89
Madhya Pradesh	4.28	8.41	1.97
Maharashtra	1.08	1.74	1.61
Punjab	3.52	15.17	4.31
Rajasthan	2.39	7.50	3.13
Uttar Pradesh	9.67	27.52	2.85
Uttarakhand	0.40	0.85	2.14
West Bengal	0.32	0.85	2.68
All India	28.46	80.80	2.84

Source: FAI (2010-11) and Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India (2011)

## TAXONOMY AND CLASSIFICATION

Domestication of wheat and the increase in ploidy (from diploid to tetraploid to hexaploid) had a great effect on its morphology and physiology. Modern wheat has larger leaves, reduced tillering phase, fewer but larger and heavier spikes and reduced to almost nil shattering (Simmons, 1987). Grain filling in modern wheats is more dependent on photosynthates from leaves and stems than from spikes, and grain yield can be largely attributed to the greater distribution of the above-ground mass to the grain. Jensen (1978) also observed that a decline in plant height was associated with a substantial improvement in yield. This partly explains higher yield associated with dwarf Mexican wheat, introduction of which led to the Green Revolution, truly speaking a wheat revolution, in India.

The cultivated wheats of today constitute an allopolyploid series, diploids through hexaploids. From the study of morphological similarities between diploid wheat *T. monococcum* L. and tetraploid wheat *T. turgidum* L., it is clear that gene 'A' of the polyploidy wheats came from *T. monococcum*. Archaeological evidences also indicate that diploid wheat that contributed 'A' gene to the tetraploid was a wild form. The source of some of 'D' gene in hexaploids was *T. tauschii* (Kimber and Sears, 1987). As regards 'B' gene there are different opinions and the donor could be *T. speltoides* (Sarkar and Stebbins, 1956) or *T. longissimum* (Feldman, 1970, 1979) or *T. urartu* (Johnson, 1975).

On the basis of genomic constitution, wheats grown in India belong to three classes, namely diploid emmer wheat (*T. monococcum*) (AA), tetraploid durum wheat (*T. durum*) (AABB) and hexaploid bread wheat (*T. aestivum*) (AABBDD). A brief discussion on these follows.

## CATEGORIZATION OF INDIAN WHEATS

In addition to grain size, boldness and luster, protein content and gluten strength are the criteria for categorizing wheat into strong, medium and soft wheats.

### Bread wheat

Bulk of the wheat area is under bread wheat and more than 85% of the wheat produced in India is consumed as '*chapati*' (unleavened thin circular bread). There are four categories in this group (Mishra, 2007).

1. *Indian amber wheat (IAW)*: Grains are bold, plump, amber, translucent and lustrous with about 11% protein. It has medium strength dough and is popular among the elite group of people, who can afford a little higher price. Some of the varieties are: C 306, Sujata, HD 2781, HD 2189, HD 2833, UP 262, HW 2004, HW 2045, LOK 1 and Raj 3077.

2. *Indian sona wheat (ISW)*: Grains are medium in size, plump, translucent with medium hard texture and a protein content of about 10% with medium gluten strength. It is grown all over the country with the largest production from NWPZ and CZ. Some of the varieties are: HD 2285, HD 2733, HD 2643, HD 2687, PBW 343, PBW 373, UP 2338, UP 2425, WH 542, WH 147, HP 1731, HUW 234, GW 193 and GW 190.



3. *Indian pissi wheat (IPW)*: Grains are medium sized. White, opaque and contain less than 10% protein. It is produced in NEPZ, CZ and NHZ of India. It is suitable for making biscuits, cakes and other bakery products. Some of the varieties are: Sonalika, Pissi Local and HB 208.

4. *Indian hard wheat (IHW)*: Grains are medium bold, translucent and hard with about 12% protein. It is most suitable for making bakery bread. It is grown in north and western Maharashtra, Karnataka and Gujarat and parts of Madhya Pradesh. Some of the varieties are: Raj 1482, GW 496, DWR 162, DWR 195, HI 977 and K 9107.

#### **Durum wheat**

Durum wheat covers about 3% of the total area under wheat in India and is restricted to central and peninsular zones. Grains are bold, lustrous, translucent and hard textured with more than 12% protein and are fairly good in  $\alpha$ -carotene and low yellow berry. It is good for making pasta (vermicelli, spaghetti, macaroni etc.). Other products include porridge, sweets, *bhapale*, *rotela*, *chapati* etc. Fresh *chapatis* made with durum wheat emit an appetizing aroma, which makes them costlier. Some of the varieties are: HI 8498, HI 8381, HD 4172, PDW 233, WH 896, MPO 1066.

#### **Emmer wheat**

Emmer wheat, commonly known as *khapal/samba/sajjaka/jave/sajjage* is traditionally cultivated in Karnataka, southern Maharashtra, Saurashtra region of Gujarat and some parts of Tamil Nadu and Andhra Pradesh. It covers only 0.5 million ha and the approximate production is 0.35 million tonnes. The grains are long, medium bold and hard textured. It remains in vegetative phase for a longer period and is more heat-tolerant than *T. durum* and *T. aestivum*. It also possesses a high degree of resistance to stem and leaf rusts. It is richer in protein (about 13%) and  $\beta$ -carotene and has gained some importance from the view point of making pasta (vermicelli, spaghetti, etc.).

### **VARIETAL DEVELOPMENT**

Simple selection exercise by wheat farmers and plant breeders for centuries resulted in the development of high-yielding cultivars. Traits such as increased number of fertile florets, length and density of spike, reduction in shattering, disease resistance and greater responsiveness to fertilizers without lodging have been genetically introduced by recent tools of mutation and hybridization. Release of a semi-dwarf variety in 1961 by crossing the Japanese cultivar Norin 10 with American winter wheat Brevor opened the era of modern wheat production. The International Maize and Wheat Centre (CIMMYT) in Mexico is the major wheat germplasm repository of the world, while the International Centre for Agriculture Research in Dry Areas (ICARDA), Syria collects and disseminates the durum germplasm.

Earliest systematic efforts for improvement of wheat germplasm in India began at the Imperial now Indian Agricultural Research Institute (IARI), Pusa, Bihar (Howard and Howard, 1906). They released local *T. aestivum* cultivars,



Sarbati, Dara, Hard red Calcutta, Bansi, Malvi and Kandwa of the durum type, Kapli, Samba and Poptia of *T. dicoccum* were distributed in several parts of Indian subcontinent. Several other significant achievements were made at the IARI, New Delhi by the wheat improvement programme led by Dr B.P. Pal. The introduction of semi-dwarfs in 1963 provided a spurt in wheat production in India. Mexican dwarf varieties Sonora 64 and Lerma Rojo, introduced in 1963, possessed higher yield levels, non-lodging trait, coupled with greater response to fertilizer nitrogen. This enthused the Indian Government to import 1,800 tonnes of seeds of Lerma Rojo and Sonora 64 in 1965. Further genetic advancement in these varieties resulted in Indian versions of dwarf and semi-dwarf genotypes named Kalyan Sona, Sonalika, UP 301 etc. The rapid increase in wheat yield in late sixties is generally termed the Green Revolution. A large number of high-yielding varieties have been developed in India. A list of varieties released and recommended for different states is given in Table 2.5.

### THE PLANT

#### Root

Like other members of grass family, the root system of wheat has two components as discussed below.

*Primary or seminal root system:* The seminal roots arise from the embryo at the time of seed germination and absorb nutrients for the young seedlings. As plant growth progresses, the primary root system gradually dies and is replaced by a permanent secondary root system.

*Secondary root system:* The permanent adventitious roots also called clonal roots arise at a point above the primary root system and emanate from lateral nodes after the appearance of the first leaf. Most of the roots are confined to the top 30 cm soil layer. However, in deep and well-drained soils, wheat roots may penetrate to a depth of two meters. In wheat, the transitional zone between the root and the shoot is called the crown. It is formed near the soil surface owing to the elongation of the mesocotyle regardless of the depth of sowing. Roots emanating from the crown are known as crown roots and crown-root initiation is an important stage for irrigating wheat.

#### Shoot

Shoot system of wheat comprises all plant parts above the ground. It consists of stem, leaves and inflorescence.

*Stem:* The wheat stem is erect, cylindrical and smooth. The nodes are solid, but internodes are hollow in most of the wheat types and varieties. However, in a few varieties of macaroni wheats the internodes are completely filled with soft pith, which imparts resistance to insects and lodging. The wheat stem generally has six nodes; the range being 5-7. The basal internode is the shortest and subsequent internodes are progressively longer. Leaf sheaths cover the internodes to a certain extent. The length of the stem is determined genetically; it is 30-100 cm in dwarf wheats and 150-160 cm in tall wheats. Stem length is also influenced by environment and soil fertility. The colour of stem is usually cream or golden yellow but some varieties also have purple coloured stem.



<b>N-W Plains Zone (NWPZ)</b>	HD 2687, HD 2428, HD 2204, CPAN 3004, Raj 307, PBW 154, WH 542, UP 2338, Raj 3765, PBW 343, DBW 17, PBW 550, PBW 502, WH 542, PDW 291(d), PDW 233 (d), WH 896(d)	HD 2285, HD 2688, HD 2270, PBW 226, Raj 3077, UP 2338, PBW 435, UP 2425, PBW 590, WH 1021, DBW 16, PBW 373, RAJ 3765	C 606, IWP 72, Kundan, WL 410, PBW 175, PBW 396
<b>N-E Plains Zone (NWPZ)</b>	Janak, UP 262, HP 1102, UP 2003, HUW 206, HD 2407, K 7410, K 9107, Vaishali, K 1006, HP 1739, K 617, HP 1761, HYW 468, NW 1012, BW 39, CBW 38, Raj 4120, K 307, HD 2824, PBW 443, PBW 343, HD 2733, HUW 468	HD 2307, HD 2285, HD 2643, HP 1209, HUW 234, K 8020, K 8962, BW 11, HP 1744, HW 1014, HW 2045, DBW 14, NW 2036, NW 1014, HP 1744, Haiba	C 306, K 8027, K 8962, K 9465, HDR 77, HD 2888
<b>N-W Hills Zone (NHZ)</b>	CPN 1796, HB 208, HD 2380, SS 240, UP 1109, BW 738, VL 804, VL 738, HS 240 For high altitude: HS 365, VL 832, SKW 196	WL 421, CPAN 1796, HB 208, HD 2380, HS 240, UP 1109, HPW 42, HS 365, HPW 42, HS 490, VL 892, HS 420, HS 295	SS 277, SS 207, HS 295, VL 804, VL 738, HS 240, TL 2942(Trit), VL 829, HPW 251, VL 616
<b>Central Zone (CZ)</b>	Kanchan, Raj 1555, HI 1544, HI 8381, Lok 1, GW 1139, GW 273, GW 322, GW 366, MH 147, HI 1077, HD 2236, DL 803-3 (50.3)	GW 173, Sonalika, Vidisha Lok 1, J 405, Swati, HD 2327, HD 2932, HD 2864, MP 1203, MP 4010	Narmada 4, NY 65, JU 12, Mukta, C 306, Meghdoot, Sujata, HI 153, HI 1500, HW 2004, Sujata, HI 8627(d), HD 4672(d)
<b>Southern Hill Zone (SZ)</b>	DWR 162, HD 4502, Kirti, HW 1085, HW 2189, HD 2380, DWR 39	DWR 195, Sonalika, HI 977, HD 2501	MACA 1967, NI 5439, N 59, Vjingga Yellow
<b>Peninsular Zone (PZ)</b>	GW 322, HUW 510, DWR 162, HD 2189, MACS 2971, HI 8663(d)	PBW 533, HD 2932, HD 2833, Raj 4083, NIAW 34	PBW 596, K 9644, HD 2781, NI 5439, AKDW 2997-16(d)
<b>Marginal areas (Salinity-alkalinity condition)</b>	KRL 210, KRL 213, KRL 19, KRL 1-4		
<b>Very late sowing</b>	Raj 3765, PBW 373, Haiba		
<b>Summer sowing</b>	HS 375		

N-W, North-western; N-E, North-eastern; d, durum

**Leaf:** Each leaf has sheath and a blade. At the junction of sheath and blade there is a ligule and two auricles. These components of leaf help in identifying different varieties.

**Inflorescence:** The wheat inflorescence is called spike or ear. It consists of a main axis or rachis around which 15-20 spikelets are closely grouped together in a zigzag manner. The spikelets emerge from a shallow depression on the rachis. The spikelets are sessile and are composed of flowers called florets. The number of florets in a spikelet may vary from 1 to 5. The florets in each spikelet are enclosed by two glumes. These glumes are called lemma and palea. If an awn is present it is attached to the lemma. In between the lemma and palea are three stamens and the ovary. The wheat ovary has an ovule and two feathery stigmas.

**Grain:** Wheat grain is a caryopsis. It is oval in shape; one side is convex, while other is flat and has a longitudinal furrow between the two protruding noitals. The tip of grain may have a tuft of hair called the brush. Wheat grain consists of an embryo, bran and endosperm.

## GROWTH STAGES

### Vegetative phase

Vegetative phase includes germination, crown-root growth, tillering, jointing, culm elongation and heading.

**Germination:** When the wheat grain is exposed to moisture, water is absorbed and the grain swells. At appropriate temperatures the embryo begins to push out both the coleorhiza and coleoptile. The seed coat is ruptured, the coleoptile turns upwards, and the primary root pierces the coleorhiza and thrusts downwards. As the coleoptile continues to elongate, the first foliage leaf of the plumule pushes through the vent. As growth continues, the second foliage leaf pushes out and seminal root grows. Germination generally takes about 5-7 days depending upon temperature.

**Crown-root development:** Coronal roots arise from the node of the first foliage leaf and this becomes the first node of the crown. The crown-root initiation (CRI) occurs in the dwarf wheat about 20-25 days after sowing (DAS). The crown roots comprise several nodes. Two, three or more coronal roots are formed at each crown node. These crown roots together with their branches are principal supply roots of the plant. Adequate moisture supply is important at this stage and that is why first irrigation in dwarf wheats is recommended between 21 and 25 days after sowing (DAS).

**Tillering:** A bud primordium lies in the leaf axil at each crown node. The bud primordia develop into tillers. Tiller production in wheat often starts about 15 DAS with a new tiller added every 4-5 days until 45 DAS. Though tillering is a varietal character, it is also affected by environmental, edaphic and agronomic factors, viz. temperature, light intensity, day length, soil moisture, fertility status, depth of sowing, spacing between plants and the preceding crop etc.

**Jointing:** This is the peak plant growth stage starting from 45 to 60 DAS. The upper and intermediate nodes expand during this period. The internodes become progressively longer from the base to the top. The uppermost internode is the longest. The existing leaves are pushed upwards and they increase in size.



**Reproductive phase**

The reproductive phase commences with differentiation of the growing point in a spike. It is characterized by the swelling of the uppermost internode. The spike is held inside the last leaf. This last leaf is called flag leaf. The flag develops completely at this stage. The maximum leaf area of plant is observed at this stage. This stage reaches 70-85 DAS.

**CLIMATE**

Wheat is grown over a wide range of latitudes ranging between 60°N and 60°S and altitudes ranging from the sea level to an elevation up to 3,500 m in the tropics and subtropics. Normally, the most ideal conditions for wheat growth are cool and moist weather during the vegetative growth period and warm and dry weather during grain formation. Because of this reason the great wheat regions of the world are found in the temperate zones between 30-60°N and 25-40°S. Growth and reproduction of the wheat plant is largely influenced by temperature, rainfall and light.

**Temperature**

The optimum temperature for the germination of wheat is between 20 and 22°C, though wheat grain can also germinate at 4°C. At temperatures considerably above the optimum, the grains germinate irregularly and the embryo frequently dies. At temperatures as high as 35°C, the endosperm may undergo decomposition due to the activities of soil microorganisms.

The optimum temperature for vegetative growth ranges from 16 to 22°C. Greenhouse studies with controlled soil temperatures indicate that plant height, root length and tiller number decreased as temperatures rose from 22°C to 42°C. Leaves were largest at 22°C and became lighter in colour as the temperature rose above 32°C. Heading was accelerated as much as 11 days as the temperature was increased from 22 to 34°C, but it was retarded or prevented at temperature above 34°C.

During the grain development wheat requires a mean maximum temperature of about 25°C for at least four to five weeks. The temperatures above 25°C reduce the test weight of grain due to hastened maturity.

**Rainfall**

Wheat grows well in those areas where annual rainfall ranges between 250 and 1,800 mm. However, heavy rains are detrimental to wheat growth as it causes delay in sowing, waterlogging, leaching of nutrients, lodging, infestation of insect-pests and diseases. Wheat crop also cannot withstand extended periods of soil moisture stress. Rainfed wheat requires a minimum evenly distributed winter rainfall of 15 to 20 cm. Low as well as high rainfall is detrimental to wheat.

**Light**

Wheat normally flowers in the long days of spring or early summer. Short days increase the vegetative growth of the wheat plant, whereas longer days hasten the formation of inflorescence. Spring wheats usually flower



at any day length from less than eight hours up to continuous light, but the process is accelerated with an increase in day length. Winter wheats generally complete their life cycle most rapidly when given low temperatures during the early stages of growth but long days and high temperatures during the later stages of growth.

### SOILS

Wheat is grown on a wide variety of soils; the most important soils orders are: Alfisols, Entisols, Vertisols, Inceptisols, Mollisols and with irrigation on Aridisols. Since wheat is a temperate and sub-temperate region crop, it is not grown on Ultisols and Oxisols, which generally occur in tropical regions of the world. Salinity and/or alkalinity of the northern Indian wheat cultivation zone reduces crop stand and yield considerably (Singh, 1990). The threshold salinity level for wheat is at electrical conductivity (EC) 6 dS/m. Yield reduces by 50% at EC 14 dS/m.

### LAND PREPARATION

In irrigated areas, wheat is usually sown after *kharif* crops like maize, rice (Prasad, 2005), pearl millet, sorghum (grain or fodder), pigeonpea, soybean, greengram, blackgram, cowpea and groundnut. After the harvest of these crops the field is irrigated and at workable moisture the field is ploughed once or twice with disc or mould-board plough and this is followed by two to three harrowings and plankings.

Under late-sown conditions wheat follows sugarcane, *toria*, pigeonpea etc. Delay in sowing causes drastic reduction in yield. The pre-sowing irrigation for wheat may be applied in previous standing crop, so that field may be prepared immediately after the harvest of previous crop. Alternately, a no-tillage system may be followed and wheat may be sown directly using zero-tillage seed drills. This system has been practiced consistently for over 15 years, by the farmers in the Panama state of Brazil (Vieira and Kochian, 1990). In India, zero-tillage seed drills have recently been developed by the Punjab Agricultural University (PAU), Ludhiana and the Govind Ballabh Pant University of Agriculture and Technology (GBPUAT), Pantnagar. Zero-tillage system permits growing of next crop despite the short turn-around period available in intensive cropping systems such as rice-wheat or under high soil-moisture situations. Weed control by herbicides is a prime requirement of zero-tillage system. Zero-tillage system invariably involves incorporation of part or entire residue of the previous such as of rice in rice-wheat cropping system. Prasad *et al.* (1999a) reported that residue incorporation is not detrimental to crop yield of succeeding crop, on the contrary it improves soil fertility. Available research data from US also support this (Prasad and Power, 1991).

In rainfed areas, collection and conservation of soil moisture and timely cultivation is the key for the success of wheat crop. One deep chiseling once in three or four years should be done to break the hard pan created by the continuous use of the country plough. Two to three summer ploughings have been found useful for permitting rain water to penetrate deeper. After cessation



of the monsoon all the possible efforts should be made to conserve moisture. The ploughings (3-4) should be done in the evening, furrows should be kept open whole night and planking should be done after each ploughing early in the morning.

## SEED AND SOWING

### Selection of seed

Seed should be healthy and of right variety recommended for a particular area. This should be clear of the seeds of other crop/variety or weeds. It should be purchased from a reliable source and should be treated with vitavax 75 wp @ 2.5 g/kg, carbendazim (Bavistin 50 wp @ 2.5 g/kg) or tebuconazole (Raxil 2 DS @ 1.25 g/kg seed.

### Time of sowing

Time of sowing is one of the agronomic practices which affects (Bhardwaj, 1978) the yield most. Time of sowing depends on the soil and climatic conditions and other facilities like irrigation availability. The optimum time of sowing for wheat is when the mean daily temperature is  $23 \pm 3^{\circ}\text{C}$  and for good tillering temperature should range between  $16^{\circ}$  and  $20^{\circ}\text{C}$ . Under irrigated timely sown condition, wheat sowing may be done in the first fortnight of November in NHZ, NWPZ and PZ and in the middle of November in NEPZ and CZ. Under late-sown conditions, the wheat sowing may be done in the first fortnight of December in NHZ, NWPZ, NEPZ and CZ, whereas in PZ it shall be done in the last week of November to first week of December. Varieties recommended for timely and late-sown conditions are given in Table 2.5. In irrigated areas long-duration (135-140 days), high-yielding, semi-dwarf varieties like HD 2967, HD 2329, PBW 502, CPN 3004, UP 368, UP 2003, WL 711 etc. should be sown between 10 and 30 November. Under late-sowing conditions (first fortnight of December), short-duration (120-125 days) varieties like Sonalika, HD 2285, HD 1553, WR 544, UP 115, UP 262 should be sown. However, if the sowing of wheat is delayed beyond 15 December, there is drastic reduction in yield despite following the best production technology. The changes in phenophases of wheat due to delayed sowing are given in Table 2.6.

Rainfed wheat is generally sown from the second fortnight of October to early November to realize the maximum advantage from the residual soil moisture.

**Table 2.6** Phenophases in wheat under timely and late-sown conditions

Parameters	Normal sowing	Late sowing
Days to anthesis	86(82-92)	76(71-83)
Days to maturity	129(120-140)	103(93-111)
Grain development (days)	43(34-52)	27(22-35)
1,000-grain weight (g)	39(32-43)	37(31-41)
Grain yield (tonnes/ha)	3.9(2.3-5.7)	2.8(2.1-3.7)

Source: Nagarajan *et al.* (2008); figures in parentheses indicate the range.



### Method of sowing

**Broadcasting:** It is a primitive but widely prevailing method of wheat sowing. Seeds are broadcast on soil surface, then worked in by harrowing and covered by planking. However, all the seeds broadcast do not get proper contact with moist soil. Secondly, some seeds are left uncovered and are eaten away by birds. This results in poor and uneven germination. To overcome these impediments, 25% higher seed rate is recommended for broadcasting. However, in the rice-wheat cropping system this method is gaining popularity due to a short turn around period between rice harvest and wheat sowing. Furthermore, broadcast wheat immediately after rice harvest gets the benefit of stored soil moisture and generally there is a good germination.

**Zero or no-tillage sowing:** To overcome the problem of short turn around period between rice harvest and wheat sowing, rotavator-cum-drills have been developed by the GBPUAT, Pantnagar and Directorate of Wheat Research (DWR), Karnal. These machines permit direct sowing of wheat immediately after rice harvest, without primary tillage. Direct seeding of wheat in rice fields without primary tillage has considerably gained popularity as a conservation technology programme launched by IRRI-CIMMYT. In over 200 on-farm trials, grain yield of wheat was 3.5 tonnes/ha in zero-till as compared to 3.0 tonnes/ha in conventional tillage sown wheat (Singh *et al.*, 2009) (Table 2.7). Net income in zero-till fields was considerably higher owing to zero cost in preparatory tillage. Similarly, in a two-year on-farm trial in Mirzapur district of Uttar Pradesh, wheat yield obtained with zero-till seeding (+1.5 kg pendimethalin/ha) was 4.9 tonnes/ha as against 2.3 tonnes/ha obtained with the farmer's conventional seeding. In addition, population of *Phalaris minor* was 5-10% and that of *Cynodon dactylon* was 6-11% lesser in zero-till wheat than in conventionally tilled wheat. Further in 80 farm demonstrations the average wheat yield in zero-till seeded and conventionally seeded wheat was 4.1 tonnes/ha and 2.6 tonnes/ha respectively.

**Behind the plough:** In this method, the seeds are dropped by hand into the furrows that have been opened with a country plough. When seed is dropped in furrows by hand, it is called '*kera*' method and when seeds are dropped through a *pora/nai/hazara* a special attachment with local plough it is called *pora* method. In this method, seeds are dropped at a desired depth and germination is satisfactory.

**Drilling:** Drilling of seed with the help of seed drill or fertilizer-cum-seed drills is the best method of sowing. Seed drills can be calibrated at an optimum seed rate. The seed drills drop the seed at an optimum depth and spacing.

**Dibbling:** Dibbling is used when quantity of seed is limited. Sowing is done with the help of a small implement known as dibbler. In this method, dibblers are pressed into the soil to make the holes and one or two seeds are dropped by hand in each hole and seeds are then covered. Though the method greatly economises the seed quantity, it cannot be commercialized because it is time-consuming and labour-intensive.

**FIRB system:** The furrow-irrigated raised bed (FIRB) system has been developed and is being promoted by the Rice-Wheat Consortium of the CGIAR



Institutes. In this method, wheat is sown on raised beds accommodating 2-3 rows of wheat. Between the beds are furrows that are used for irrigation. This system permits adequate saving in irrigation water. The yields obtained are similar to or more than conventional seeding. For example, in one study at the DWR, Karnal, FIRB system gave an average yield of 5.45 tonnes/ha, while the conventional sowing gave 5.34 tonnes/ha. In a recent on-farm study in Ballia district of Uttar Pradesh, FIRB-DSW wheat gave the highest yield and economic returns (Table 2.7). Special raised bed-making and planting machines have been developed for this purpose. The FIRB technology has potential to reduce the cost of cultivation and also to minimize dependence on herbicide for weed control.

**Table 2.7** Yield and economics of wheat production under conventional and conservation technologies in on-farm trials in Ballia district Uttar Pradesh

Treatment (Tillage)	Grain (tonnes/ ha)	Production cost (₹/ha)					Net income (₹/ha)	
		Seed	Seeding	Fert- ilizer	Herb- icide	Total		
CT-BCW	3.0	1,980	1,890	45	2,790	270	6,975	19,875
ZT-DSW	3.5	0	1,485	1,080	2,475	225	5,265	27,136
FIRB-DSW	4.4	1,710	1,395	1,440	2,385	270	7,200	33,284

CT-BCW, Conventional tillage, broadcast wheat; ZT-DSW, Zero-till drill seeded; FIRB-DSW, furrow irrigated raised bed-drill seeded wheat; Need-based herbicide glyphosate or paraquat was applied in all the treatments; Original data in US\$ converted to ₹ taking 1 US \$ = 45 ₹

Source: Singh *et al.* (2009)

### Seed rate

Seed rate of wheat varies with varietal characters like seed size, tillering ability and germination percentage, time of sowing, moisture content in the soil at sowing and time and method of sowing. Under normal conditions, a seed rate of 100-125 kg/ha is sufficient. A variety of higher test weight and shy in tillering requires higher seed rate. Under late-sown conditions, seed rate should be increased by 25%. Seed rate of 100 kg/ha at 38 g/1,000 seeds is required under irrigated timely-sown conditions. In case of FIRBS, seed rate may be reduced to 75 kg/ha. Similarly, when soil moisture is less at sowing time, seed rate should be increased by 25% seed/ha. Sowing with plough and seed drill requires 125 and 100 kg seed/ha, respectively, under normal conditions. For dibbling a seed rate of 25-30 kg/ha is sufficient.

### Spacing

Spacing varies with variety, time of sowing and irrigation. A wheat variety that tillers excessively is spaced widely. Irrigated wheat is spaced 22.5 cm between rows and 8-10 cm between plants. Rainfed wheat is spaced 25-30 cm between rows and 5-6 cm between plants. When sowing is delayed, a closer spacing of 15-18 cm between rows is recommended. Narrow spacing coupled with higher plant density generally helps in the suppression of weeds. Seeding depth should be around 5±2 cm.



### NUTRIENT MANAGEMENT

Wheat responds well to NPK fertilization all over the country and a rapid increase in fertilizer use started with the introduction of dwarf Mexican wheats and the total  $N+P_2O_5+K_2O$  consumption almost doubled from 0.78 million tonnes in 1965-66 to 1.54 million tonnes in 1967-68, the year of Green Revolution in India. There has been no looking back in the fertilizer consumption since then and in 2010-11, 28.1 million tonnes of  $N+P_2O_5+K_2O$  were consumed; about 55% of this was in the major wheat-growing states.

Some data on response of wheat to NPK fertilization from on-farm trials in India are given in Table 2.8. Control (no fertilizer) yield as well response to NPK was the highest in Punjab. Although the control yields were lower, response to N in Haryana and Bihar was as good as in Punjab; response to P was higher in Haryana and Bihar than in Punjab mainly because Punjab farmers have been applying P in their field for quite some time in the past that has increased available P level of soils. Response to P was the highest in Himachal Pradesh. Response to K was the highest in Punjab and Bihar, followed by that in Maharashtra. It was also reasonably good in Madhya Pradesh and Haryana. These results bring out the need for balanced NPK fertilization in all wheat-growing states of India.

**Table 2.8** Response of wheat to NPK fertilization in different wheat-growing zones of India

Zone	State	Trials (Nos)	Control (tonnes/ha)	Response (kg grain/kg nutrient)		
				N	$P_2O_5$	$K_2O$
NHZ	Himachal Pradesh	52	2.1	4.8	20.4	5.6
NWPZ	Haryana	70	2.0	11.6	14.1	9.3
	Punjab	48	3.1	11.0	11.7	14.3
NEPZ	Bihar	46	1.0	11.0	12.9	13.7
CZ	Madhya Pradesh	153	2.0	4.1	7.4	9.5
PZ	Maharashtra	72	1.9	4.6	10.0	11.1

*Source:* Indian Agricultural Research Institute, New Delhi; Trials conducted under the aegis of PDFSR, Modipuram, Uttar Pradesh

The general  $N+P_2O_5+K_2O$  (kg/ha) recommendations for irrigated wheat are 150+50+25 in Himachal Pradesh, 150+60+0 in Uttarakhand, 120+60+30 in Punjab and Haryana, 150+60+60 in western Uttar Pradesh, 120+60+40 in eastern Uttar Pradesh and Madhya Pradesh, 120+60+20 in Bihar, 120+40+40 in West Bengal, 100+50+50 in Maharashtra, 120+60+0 in Gujarat, 90+30+30 in Rajasthan (NAAS,2009). For rainfed wheat the recommendation is about 80+40+20 kg/ ha.

#### Nitrogen

The wheat plant absorbs much of its nitrogen by the time of flowering, but absorption of nitrogen continues till maturity. The critical concentration of nitrogen in wheat leaves is reported to be 2.5% below which deficiency



symptoms appear. In the absence of adequate supply of nitrogen, wheat plants turn yellow and growth becomes stunted. There is poor tillering and few tillers bear small ear heads. Grains are also not fully developed. All of these result in poor yield. Indian soils are universally deficient in nitrogen and call for adequate nitrogen application.

Under irrigated conditions, nitrogenous fertilizers should be applied in two to three equal splits. In medium and heavy soils, two-thirds or half of the dose should be applied at the time of sowing and remaining one-third or half dose should be top-dressed at first irrigation. On sandy soils, top-dressing should be made in two splits; at first and second irrigation. Generally, advantage of more splits is seen with higher level of N application. Under rainfed conditions, full dose of nitrogen should be placed before sowing. If there is good rainfall during crop growth, an additional dose of nitrogen may be top-dressed for high yield.

Most nitrogenous fertilizers presently marketed in India are equally effective, but on calcareous and strongly alkaline soils, 10-30% of top-dressed urea nitrogen may be lost through ammonia volatilization (Sarkar *et al.*, 1985; Prasad *et al.*, 1999b). Under such cases ammonium sulphate may perform better than urea (Singh and Prasad, 1985).

### Phosphorus

Phosphorus is a critical nutrient for wheat growth, particularly for dwarf wheats; about 25% increases in response to NPK application is attributed to P (Table 2.9). In general, in maize-wheat, sorghum-wheat and *bajra*-wheat rotations adequate P fertilization of wheat can meet the P requirement of the entire rotation. Although this is suggested for rice-wheat system also, there are evidences that in rice-wheat cropping system both the crops may have to be fertilized with P (Prasad, 2007).

Phosphorus absorption takes place at a rapid rate throughout the crop-growth period and its accumulation in the plant reaches the maximum about two weeks before the maturity. P concentration below 0.1% in dry leaf tissue is considered deficient. Phosphorus-deficient wheat plants bear less as well as

**Table 2.9** Response of irrigated wheat to N, P and K in on-farm trials conducted during 1971-82

State	Traits	Yield without fertilizer	Response to 120-60-60 kg N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O/ha	Per cent contribution of		
				N	P	K
HP	85	1,410	2,370	46	28	26
Punjab, Bihar, UP	1,400	1,770	2,620	61	23	16
Odisha, MP	882	1,110	1,710	44	33	23
MP, Maharashtra	1,145	1,380	1,480	58	22	20
Karnataka	250	1,260	1,130	44	28	28
Mean	3,768	1,450	1,950	56	25	19

HP, Himachal Pradesh; UP, Uttar Pradesh; MP, Madhya Pradesh

Source: Pillai *et al.* (1985)



smaller ears. Phosphorus deficiency also reduces the number and size of grains. Soil P concentration up to 8 ppm (Olsen's P) is often considered low. It necessitates external P application. The crop yield responses have been observed up to 60 kg  $P_2O_5$ /ha. However, response to P depends on the source and concentration of water-soluble P in the fertilizer, in addition to many other relevant soil factors. On neutral and alkaline soils, phosphatic fertilizers containing at least 50% of total P in water-soluble form are more efficient as compared to those fertilizers which contain less water-soluble P (Prasad and Dixit, 1976). There are some reports of direct application of ground rock phosphate; however, its efficiency is much lower than ordinary superphosphate or other forms. Sharma and Prasad (1996) recommended mixing of rock phosphates with pyrites for higher efficiency on neutral soils of Delhi (Table 2.10). On acid soil (pH less than 6), use of rock phosphate and basic slag is more profitable than superphosphate or diammonium phosphate (Prasad and Dixit, 1976).

Water-soluble phosphatic fertilizers such as diammonium phosphate and superphosphate are more efficient when applied in granular form and are placed near seed band, whereas citrate-soluble and insoluble fertilizers are more efficient in their finely powdered form and when they are mixed with large volume of soil. Phosphatic fertilizers are generally recommended to be applied at sowing. However, when phosphorus is not applied at sowing it should be applied at the time of first irrigation.

### Potassium

The data from the on-farm trials conducted in India have always shown a definite response of wheat to K. Tiwari (1974) also reported that wheat responds to potassium up to 40-50 kg  $K_2O$ /ha in the Indo-Gangetic alluvium on the soils having low to medium level of potassium. Most of the potassium in wheat is absorbed by seven weeks before the maturity of the crop. Potassium deficiency adversely affects the grain productivity as well as quality. The response to potassium largely depends on its soil status. Therefore the correct level of its application should be decided on the basis of soil test values. Muriate of potash (potassium chloride) and potassium sulphate are only potassic fertilizers presently available in the market. Both are equally effective for wheat. Potassic fertilizer should be applied at the time of sowing; however, it can also be top-dressed at the time of first irrigation.

**Table 2.10** Relative efficiency of phosphate fertilizers for wheat (averaged over 20 and 40 kg  $P_2O_5$ /ha and pooled over 2 years of study)

Source of P	Grain yield (tonnes/ha)
Rock phosphate	3.9
Rock phosphate + pyrite	4.6
Nitrophosphate (60% wsp)	4.9
DAP	4.9
Ammonium polyphosphate	5.3
CD (P = 0.05)	0.3

\* WSP, Water-soluble P as percentage of total  
Source: Sharma and Prasad (1996)

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### Sulphur

About 41% of Indian soils are deficient in sulphur and response of wheat to S has been reported from almost all the states (Singh, 2001). The critical S deficiency level using Williams and Steinberg (1959) method is <10 mg/kg soil. Substitution of high analysis fertilizers such as urea and DAP for ammonium sulphate and single superphosphate has been the main cause for widespread S deficiency in Indian soils. The other important factor has been the high harvests of crops resulting in heavy removal of native soil sulphur.

In the TSI-FAI-IFA trials conducted during 1997-2006, the increase in wheat yield due to S fertilization was 30% (Tewatia *et al.*, 2007). Symptoms of S deficiency in plants are similar to that of N, but it can be differentiated on the following points.

- In most crops the younger leaves turn yellow due to S deficiency. In contrast it is the older leaves that turn yellow due to N deficiency.
- S deficiency cannot be corrected even with heavy application of N.
- In S-deficient plants S levels in plant tissue are lower, while N levels are higher.

**Sources of S:** There are two kinds of S fertilizers. The first kind are the popular fertilizers containing S as the nutrient other than that for which fertilizer is applied. For example, single superphosphate (SSP) is marketed as phosphate fertilizer but contains 12% S. Other examples of such sulphur fertilizers are ammonium sulphate (21% N, 24% S), ammonium sulphate nitrate (26% N, 15% S), ammonium phosphate sulphate (16-20% N, 20% P<sub>2</sub>O<sub>5</sub>, 15% S), potassium sulphate (48% K<sub>2</sub>O, 18% S) and zinc sulphate hepta hydrate (21% Zn, 15% S). The other kind of S fertilizers are those materials, which are marketed and used only as a source of S. These include elemental S, gypsum (13-14% S, mostly used for reclaiming sodic soils), iron pyrites (22-24% S) and phosphogypsum (13-18% S, a byproduct of phosphoric acid industry) and elemental S (99.6% S). Sulphur in pyrites is present as sulphide and must be oxidized before it becomes available to crop plants. Oxidation of pyrites is faster if it is applied on the surface rather than its incorporation in soil. S as elemental S has also to be oxidized before it becomes available to crop plants. Although differences in relative performance of various sources of S have been reported, in general, all sources of S have been found to be equally effective (Singh, 2001). Most S is applied to soil at sowing.

### Micronutrients

Deficiency of micronutrients like Zn, Fe, Cu, Mn and B in wheat has been reported (Takkar, 1996) but Zn deficiency in wheat is most widely reported (Patel, 2011). For the most common sources of micronutrient fertilizers see Table 1.9 in Chapter on Rice. A brief discussion on individual micronutrients is given here.

**Zinc:** Zn deficiency leads to retardation of stem elongation, necrosis and chlorosis of leaves. In wheat plants at 8-30 cm growth, 15 ppm Zn represents deficiency, 15-150 as sufficiency and > 150 ppm as toxicity (Katyal and Randhawa, 1983). In 35 days old wheat leaves < 10 ppm Zn represents acute deficiency of Zn (Agarwal and Sharma, 1979). Higher levels of P in soil may interfere with Zn availability in soil.



Zinc is commonly applied in the form of commercial grade zinc sulphate @ 25 kg/ha (21% Zn). Zinc sulphate should preferably be placed in soil at the time of sowing. However, its deficiency if noticed during the early growth stages could be corrected by a foliar spray of  $ZnSO_4$  (0.5%). For this 5 kg of  $ZnSO_4$  and 2.5 kg of slaked lime is dissolved in 1,000 litres of water to spray an area of 1 ha.

**Manganese:** Manganese deficiency symptoms are seen as necrotic streaks on the leaf lamina; such streaks are highly conspicuous on the flag leaf. About 181-260 ppm Mn in plants is considered optimum. Foliar spray of 0.5%  $MnSO_4$  is recommended to correct Mn deficiency. Similarly, earliest symptoms of Mn deficiency of chlorosis of wheat leaves that appear within two weeks after sowing can be corrected by foliar spray of Mn.

**Boron:** Boron deficiency has been reported from West Bengal (Mitra and Jana, 1991). Boron deficiency results in improper development of inflorescence, very short awns, and reduction in yield and grain quality. About 10-20 kg/ha borax application to soil or foliar application of 0.3% borax solution is recommended on B-deficient soils. Recently boronated NPK fertilizers have become available and a good response to their application in West Bengal has been reported (Sarkar *et al.*, 2006).

**Copper:** Copper deficiency begins as limpness or wilting with resultant loss in turgor. The tip of leaves becomes pale yellow. Reduced stem elongation, improper heading and spikelets devoid of grains are other symptoms of copper deficiency. The Cu deficiency can be corrected by a foliar spray of  $CuSO_4$ .

#### Integrated nutrient management (INM) or integrated plant nutrient supply system (IPNS)

Farmyard manure and green manures are generally applied to *kharif* crops in crop rotations when wheat is the succeeding crop. In long-term experiments, where 10-15 tonnes FYM/ha year was applied in *kharif* season, its impact on wheat yields ranged from 2 to 27% and there was a clear tendency that it increased with time. Growing short-duration legumes (greengram and blackgram) and incorporation of their residue after picking of pods before wheat has a significant residual effect on wheat yield, which was equivalent to 74-82 kg N/ha when applied as mineral fertilizer (Table 2.11). Similarly, in rainfed wheat, an incorporation of greengram and blackgram residue after picking of pods resulted in sparing 40 kg N/ha in succeeding wheat (Sharma *et al.*, 1987).

Biofertilizers also constitute an important component of the INM or IPNS. *Azotobacter* inoculation increases wheat yield by 10-30% without fertilizer N and by 11% in

**Table 2.11** Effect of rainy-season crops and their residue on grain yield (tonnes/ha) of wheat

Rainy-season crop	1988-89	1989-90
Sorghum (F)	5.35	5.10
Mungbean	5.86	5.39
Mungbean (RI)	6.04	5.87
Urdbean	5.94	5.33
Urdbean (RI)	6.33	5.85
CD (P=0.05)	0.48	0.49

F, Fodder; RI, Residue incorporated in soil

Source: Sharma *et al.* (1996)



the presence of 120 kg N/ha (Venkateswaran and Tilak, 1990). Biofertilizers have assumed importance in relation to P nutrition also. Use of phosphate-solubilizing organisms, popularly known as PSB, and or VAM mycorrhiza can help in making native soil P more available to wheat (Sharma *et al.*, 2011). They also help in improving the availability of ground rock phosphate.

### WATER MANAGEMENT

Wheat requires about 300-400 cm of irrigation water, depending upon climatic factors (rainfall, temperature, wind velocity, sunshine hours), soil characteristics and the duration of variety. About 90% of area under wheat in India is irrigated although the amount of irrigation water available and applied differs considerably from one region to another. In regions, where well water is available, the number of irrigations may vary from 4 to 6, while in regions where the farmers depend only on canal water, wheat may receive only one or two irrigations. Further, on sandy soils more irrigations are given.

#### Scheduling of irrigations

With the introduction of high-yielding dwarf wheats in India, irrigation at critical stages of wheat growth received considerable attention (Bharadwaj and Wright, 1968). These studies brought out that in dwarf wheats first irrigation should be given 20-25 DAS as against the practice of giving the first irrigation to tall Indian wheats one month after sowing. The second and third important stages requiring irrigation were found to be flowering (80-85 DAS) and dough formation (95-100 DAS). Crown-root initiation and heading stages are the most critical to moisture stress. Four to six irrigations are enough for wheat crop. Depending upon the water availability, these should be applied as per the requirement of the crop. More information on the number of irrigations to be given on the basis of availability of water is given in Table 2.12.

Climatic parameters, especially pan evaporation data, can also be used for scheduling irrigation in wheat in the areas where water resources are in abundance. Dastane and Singh (1964) at Delhi recommended irrigations at 99 mm cumulative pan evaporation (CPE) irrespective of the variety. Khuspe (1975) recommended irrigation at 60 mm CPE at Parbhani in Maharashtra. Bhan (1975) at Kanpur recommended irrigations at 100 mm CPE.

In recent years, a ratio between irrigation water (IW) and CPE has been used for scheduling irrigation in wheat. An appropriate IW : CPE ratio

**Table 2.12** Number of irrigations based on the availability of water

No. of irrigation available	Critical stages
1	CRI
2	CRI + LJ
3	CRI + B + M
4	CRI + LT + F + M
5	CRI + LT + LJ + F + M
6	CRI + LT + LJ + F + M + D

CRI, Crown-root initiation (21 DAS); LT, late tillering (42 DAS); LJ, late jointing (60 DAS); F, flowering (80 DAS); M, milk (95 DAS); D, dough (115 DAS)

Source: Pal *et al.* (1996)



for an irrigation in wheat ranges between 0.7 and 0.9. However, from the operational point of view, this method has limited applicability because CPE measurements are beyond the means of a common farmer. Moreover, the yield of wheat due to irrigations scheduled on the basis of different criteria did not differ significantly. Prihar *et al.* (1975) observed that irrigation based on IW:CPE ratio economized the irrigation water as compared to irrigations based on growth stages.

### Methods of irrigation

Border strip (length : width ratio > 4) is the most common adopted method of irrigation, followed by Check basin (length : width ratio < 4) method. The width of the strips is to be decided upon the slope and discharge of water. Agarwal and Khanna (1983) suggested border strips of 70 m × 7.5 m when the field had 0.1% slope and the discharge was 0.5 cusec (14 litres/sec). At Ludhiana, a strip width of 5 m was good when water discharge was 1 cusec (28 litres/sec) but 15-20 m was better when the discharge was 50 litres/sec (Agarwal *et al.*, 1997). The length of the strip depends upon the soil texture and is longer on medium and heavy soils than on lighter soil. On sandy soils, the check basin method may be preferred. In case of zero tillage, irrigation scheduling similar to conventional tillage may be followed.

Furrow irrigation has become possible in wheat with the introduction of FIRB (furrow-irrigated raised bed) of wheat cultivation. It certainly increases the water-use efficiency (WUE). In FIRB system, first irrigation may be applied immediately after sowing for proper germination.

**Table 2.13** Relative efficiency of surface and sprinkler irrigation in wheat

Parameter	Rahuri	Udaipur	Hisar
<i>Grain yield (tonnes/ha)</i>			
Surface	3.4	2.66	4.48
Sprinkler	3.64	3.30	4.87
<i>Irrigation water (cm)</i>			
Surface	35.0	33.0	33.9
Sprinkler	20.2(42.3)	14.5(56.0)	32.7(3.5)
<i>Water-use efficiency (q/ha-cm)</i>			
Surface	0.93	0.81	1.32
Sprinkler	1.79	2.27	1.49

Figures in parentheses are percentage reduction in water need from surface irrigation

Source: Khanna (2009)

Sprinkler irrigation is also finding its way in wheat crop, especially on light soils having sand-dunes, where border-strip or even Check-basin is not possible. Similar or even higher yields are possible with sprinkler method as compared to surface flood irrigation with a much higher WUE (Table 2.13).

### WEED CONTROL

The average loss in wheat yield caused by weeds is about 25 to 30%, but it varies depending on weed density, time of emergence, soil and environmental



factors. The critical period of weed competition in wheat is 30-45 days after sowing (Chhonkar *et al.*, 2002). Before Green Revolution broad-leaf weeds, viz. *Carthamus oxycantha* and *Chenopodium album* were dominant in wheat, but after Green Revolution weed flora shifted in favour of grassy weeds, mainly *Phalaris minor* and *Avena fatua*. This was mainly due to increased irrigation and fertilizer application. Another factor responsible for the dominance of grassy weeds is continuous use of 2,4-D which led to the eradication of broad-leaf weeds. Major weeds in wheat are:

#### Grassy weeds

*Phalaris minor* (little canary grass, *mandusi*, *kanaki*, *guli danda*), *Avena fatua* and *A. ludoviciana* (wild oats, *jangli jae*), *Cynodon dactylon* (Bermuda grass, *doob*), *Poa annua* (annual Meadow, *poa ghas*), *Polypogon monospermius* (foxtail grass, *lomari ghas*).

#### Sedges

*Cyperus rotundus* (purple nutsedge, *motha*), *C. esculentus* (yellow nutsedge, *motha*)

#### Broad leaf

*Chenopodium album* (lamb's quarters, *bathua*), *C. murale*, *Rumex retroflus* and *R. dentatus* (golden dock, *jangli palak*), *Anagallis arvensis* (pimpernel, *krishna neel*), *Convolvulus arvensis* (field bind, *hirankhuri*), *Argemone mexicana* (Mexican prickly poppy, *satyanashi*), *Melilotus indica*, *Fumaria parviflora* (fumatory, *bansoya*, *gajri*), *Cannabis sativa* (Indian hemp, *bhanga*), *Carthamus oxycantha* (wild safflower, *pohli*), *Asphodelus tenuifolius* (wild onion, *piazi*), *Cirsium arvense* (Canada thistle, *kateli*), *Coronopus didymus* (swine grass, *pitpara*), *Euphorbia helioscopia* (sun spurge, *dudhi*), *Lathyrus aphaca* (meadow pea, *matri*, *jangli matri*), *Malva parviflora* (meadow weed, *gogi sag*), *Medicago hispida* (Toothed bur clover, *maina*), *Melilotus alba* (white clover, *metha*), *Polygonum plebejum* (smart weed, *raniphal*), *Vicia sativa* (wild vetch, *chatri*), *Spergula arvensis* (corn spurr, *bandhania*).

Rice-wheat rotation in North India has created the problem of *Phalaris minor* and *Avena fatua* (wild oats) in wheat. Both the weeds normally germinate along with the wheat crop. During the initial growth stages their morphological features closely resemble the traits of wheat seedlings. Therefore it is difficult to differentiate them. Few distinguishing features by which these weeds can be differentiated from wheat plants are given in Table 2.14.

#### Weed-control methods

**Manual/mechanical:** Hand-weeding with a *khurpi* or hand-hoe 20-25 DAS used to be the conventional practice. However, due to increasing nuclear families and heavy cost and scarcity of farm labour, this practice is now restricted to poor small-holders. Also it is difficult to identify *P. minor* and *A. ludoviciana* in early stage of growth from wheat seedlings.

**Chemical:** A pre-emergence application of pendimethalin (Stomp 30 EC) @ 1 kg/ha (3,300 ml/ha) in 500-750 litres/ha of water within 3 DAS provides a

**Table 2.14** Distinguishing features of *Phalaris minor* and wild oats and wheat

Plant part	<i>Phalaris minor</i>	<i>Avena fatua</i>	Wheat
Stem	Solid, branched, pink or purple in colour at the base to 50 days of growth	Hollow, unbranched normally green in colour	Hollow, unbranched dark green in colour
Leaves	Smooth, pale green colour with purplish green spots at the junction of lamina and leaf	Green but no serration and hair are present at the margins, slightly rough	Dark green with serrated margins, pubescent and rough
Ligule	Very large	Large and serrated	Very small
Auricles	Absent, hairs present at the junction of leaf sheath and lamina	Absent, no hair at the junction of leaf sheath and lamina	Two and mostly hairy

Source: Pal *et al.* (1996)

broad-spectrum control of weeds in wheat. However, post-emergence application of herbicides is necessary for effective control of weeds, which is generally recommended 25-30 DAS. Earlier, isoproturon was generally used for the control of *P. minor*, but this weed has now developed resistance to isoproturon in several parts of the country. Isoproturon has been replaced by cladinofop, fenoxaprop-p ethyl and sulfosulfuron. It may also be mentioned that some wheat cultivars, such as HD 2009, WH 283, WH 416 and Sonak react to 2,4-D application and develop malformed spikes, resulting in reduced yield. Thus one has to be careful with the application of 2,4-D in wheat. Herbicides and their application rates for weed control in different areas are given in Table 2.15.

**Table 2.15** Herbicides recommended for weed control in wheat ( 25-30 DAS)

Area	Weeds	Herbicide	Dose (g a.i./ha)	Water (litres/ha)
After rice	Grassy	Sulfosulfuron	25	200-250
		Clodinofop	60	200-250
		Fenoxaprop-ethyl	80-120	250-300
		Tralkoxydim	350	500
		Metribuzin	175	500
After crops other than rice	Grassy	Isoproturon	1,000	500
All areas	Broad-leaf	2,4-D (sodium salt)	750	500
		Metribuzin	200	500
		Metsulfuron-methyl	4-6	200-250

Source: Sharma (2007)

### WHEAT-BASED CROPPING SYSTEMS

Under irrigated conditions wheat is generally grown after a number of *kharif* crops such as rice, maize, sorghum, millet, mungbean, urdbean, cowpea, pigeonpea, cotton, etc. These are 2 crops-a-year cropping systems. In some



regions, 3 crops-a-year cropping systems are practiced where a catch crop of *toria* or potato is taken between *kharif* crop and wheat (Sharma *et al.*, 1995a). Alternatively a catch crop of summer mungbean is also possible in wheat and *kharif* crops (Sharma *et al.*, 1995b).

In Western Uttar Pradesh wheat is rotated with sugarcane. In such cases sugarcane takes first one or two years (planted and one ratoon) and then a 2 crops-a-year rotation is taken up. Wheat is also intercropped in autumn-planted sugarcane. Wheat completes its life cycle before sugarcane picks up. This is possible because sugarcane does not tiller well during winter months of November, December and January.

Under rainfed conditions, generally fallow-wheat rotation is practiced but by timely action a short-duration crop of mungbean or urbean can be taken where rainfall is 700 mm or above (Sharma *et al.*, 1987). This can also bring considerable N economy in wheat.

### DISEASES

Wheat diseases include rusts, *Alternaria* leaf blight, loose smut, Karnal bunt and powdery mildew.

#### Rusts

Wheat is infected by brown, yellow and black rusts. Brown or leaf rust is caused by a fungus known as *Puccinia recondita tritici*. The small, round-oval uredial pustules of brown rust develop mainly on the leaves, but in severe attacks, these appear on sheath and stem as well. The uredial pustules are bright orange and appear either in small clusters or are irregularly scattered. In case of severe attack, plants mature early, produce light and shrivelled grains. Yellow or stripe rust is caused by the fungus, *Puccinia striiformis*. In the mild attack, uredia appear mainly on the leaves but in case of severe attack, uredia appear on leaf sheaths, stalks and glumes as well. The uredial pustules are oval and lemon-yellow and are formed in long streaks or rows. Usually, it is observed that the infection starts in early-sown crop (i.e. October) in the fields under poplar trees. Hence, strict watch is needed by the farmers in fields, where agroforestry with poplar is practiced.

Black or stem rust of wheat is caused by the fungus *Puccinia graminis tritici*. The uredial pustules reddish-brown in colour appear on stem, leaf sheath, leaves and ear heads in elongated shape. Black rust is a killer disease and in severe infection the crop fails.

In India, yellow rust can be severe in northern/north-western region, black rust in central or peninsular region, whereas brown rust occurs in all wheat-growing regions. Brown and yellow rusts caused severe damage to wheat crops in Uttar Pradesh between 1971 and 1973, while an epidemic of brown rust occurred in 1993 in about 4 million ha area in north-western India (Parashar *et al.*, 2007).

For controlling rusts, measures suggested are:

- (i) For avoiding the losses due to yellow rust of wheat in NWPZ, avoid planting of PBW 343 and other susceptible varieties like UP 2338, HD



2687, HD 2329, WH 711 and PBW 373. Varieties like DBW 621-50, HD 2967, WH 542, DBW 17, PBW 550, DBW 16 (late sown), WH 1080, WHD 943, PDW 314, etc. may be preferred. Special attention should be given to the epidemiologically important region, i.e. the foot-hills and plain of Jammu and Kashmir, parts of Punjab, especially along the international border and foot-hills of Himachal Pradesh.

- (ii) Treat the seed before sowing with *Trichoderma viride* @ 4 g/kg seed. It provides induced systemic resistance, thus reducing the severity of the yellow rust at later growth stages of the crop.
- (iii) Late-sown crop is more susceptible to rust. Hence avoid late sowing of wheat.
- (iv) High nitrogen dose favours rust infection, whereas high potash dose reduces rust infection. Hence there is need for balanced fertilization.
- (v) Spray the crop with propiconazole (Tilt 25 ec @ 0.1%) or tebuconazole (Folicur 250 ec @ 0.1%) or triademefon (Bayleton 25 wp @ 0.1%) at yellow rust initiation. Usually, it is required in the first half of February. This spray will also help in the control of powdery mildew and Karnal bunt diseases.
- (vi) Second and third spray may be repeated with an interval of 10-15 days.

#### Loose smut

Loose smut is caused by fungus *Ustilago nuda tritici*. Terminal symptom of loose smut is the production of black powder in place of wheat grains in the ears. Black powder is a mass of olive-green microscopic spores of smut fungus. When spores are blown to flowers of healthy plants, they germinate on the stigma and lead to infection of developing seed. The smut fungus thus reaches in the matured grain and remains dominant there until the germination of the grain. When infested grains germinate, the fungus inside the seed becomes active and grows inside the plant, keeping the pace with the apex of the growing shoot. As the ear formation starts, fungus accumulates in the floral parts, which are completely destroyed due to formation of the black powder.

Loose smut can be controlled by:

- (i) Growing loose smut-resistant varieties
- (ii) Seed treatment with a combination of the reduced dosage of the fungicide and *T. viride* is made. The bioagent fungus, apart from enhancing the efficacy of the fungicide, also leads better germination, growth and protection against diseases through induced systemic resistance. For this purpose, seed treatment should be done with *T. viride* @ 4 g/kg seed in combination with carboxin (Vitavax 75 wp) @ 1.25 g/kg seed or tebuconazole (Raxil 2 ds) @ 1.0 g/kg seed.
- (iii) Uprooting the infected plants, burying it underground or burning it.

#### Karnal bunt

Karnal bunt was first observed in Karnal (Haryana) in 1980 and is caused by fungus *Neovossia indica*. A portion of infected grain along its groove is converted into a black powdery mass. The black powder gives a foul smell due to presence of trimethylamine.



Since spores of the Karnal bunt fungus are soil-borne as well as seed-borne and infection occurs at the flowering time by air-borne sporidia, the disease is difficult to control in the absence of disease-resistant varieties. Karnal bunt control is required for seed crop and the produce grown for export purposes. The following measures can minimize occurrence of Karnal bunt.

- (i) Do not grow highly susceptible wheat varieties like HD 2009, UP 319, WL 711 and HD 1982. Variety PBW 502 is resistant to this disease.
- (ii) For management of Karnal bunt, one spray of propiconazole (Tilt 25 EC) @ 0.1 % (1 ml in 1 litre water) may be given (in seed crop only) at ear head emergence stage.
- (iii) Two sprays of biocontrol fungus, *Trichoderma viride*, one before ear head emergence, followed by another spray at ear head emergence stage, provide a non-chemical (biological control) management of disease.
- (iv) One spray of *T. viride*, followed by one spray of propiconazole (25 EC) @ 0.1% at ear head emergence stage can be given to attain near complete control. Similarly, two sprays of propiconazole give complete control of this disease.
- (v) Avoid continuous cropping of wheat in the same field.
- (vi) Avoid excessive irrigation particularly during flowering of wheat.

#### **Alternaria leaf blight**

Alternaria leaf blight is caused by the fungus *Alternaria triticina*. The disease first makes its appearance as small, oval, discoloured lesions on lower most leaves. The spots become irregular in shape, take up dark brown to gray colour and gradually spread to the upper leaves. A bright yellow marginal zone is sometimes seen around the spots. In case of severe attack, leaf-sheaths, awns and glumes are also infected. Black powdery spores are disseminated by wind and cause disease on healthy leaves and plants. *Alternaria* leaf blight can be controlled by:

- (i) Treating seed with vitavax @ 2.5 g/kg seed.
- (ii) Apply only needed amount of fertilizer and irrigation
- (iii) Spraying zineb or dithane M-45 as recommended in the case of rusts.

#### **Powdery mildew**

This disease is caused by a fungus *Erysiphe graminis tritici* and is characterized by formation of white powdery growth of the fungus on the upper surface of leaves. Later on, the colour of powdery growth becomes grey or brown. Under severe infection, leaf sheaths, stems and ear heads may also be covered by the fungus, plants become stunted and produce poor yield. The disease can be controlled by:

- (i) Keeping optimum plant population, dense crop should be avoided.
- (ii) One spray of propiconazole (Tilt 25 EC) @ 0.1 % at ear head emergence or appearance of disease (whichever is earlier) is recommended for the powdery mildew-prone areas.



### INSECT-PESTS

Wheat crop is attacked by a number of insect-pests and rodents. Only a few most important ones are discussed here.

#### Termites

The damaged plants dry up completely and can be easily pulled out. Infestation is heavy under unirrigated conditions and in the fields where undecomposed farmyard manure is applied before sowing. Termites (*Odontotermes obesus*, *Microtermes obesi*) can be controlled by seed treatment with chlorpyrifos @ 0.9 g a.i./kg seed. Seed treatment with thiamethoxam 70 ws (Cruiser 70 ws) @ 0.7 g a.i./kg seed or fipronil (Regent 5 FS @ 0.3 g a.i./kg seed) is also very effective. In the standing crop, the broadcasting of the insecticide treated soil 15 days after sowing (DAS) be practiced. For this, chlorpyrifos @ 3 litres mixed in 50 kg soil be used for 1 ha field. Crop planted under FIRBS is more prone to termite attack in the termite-prone areas, while zero tillage shows less termite damage. Hence, proper attention should be given in crop planted under FIRBS.

#### Army worms

Caterpillars or army worms (*Mythimna separata*) feed on the plants during the night and hide during the day time. They may be controlled by spraying 500 ml Nuvan (dichlorvos) 85 sl. or carbaryl (Sevin 50 wp) @ 2.5 kg/ha or 1 litre Ekalux 25 ec (quinalphos) in 300-400 litres of water.

#### Rodents

Field rats also cause heavy loss to wheat in field. For the control of field rates fumigate the burrows of rats with aluminium phosphide @ 1 tablet of 0.5 g/small burrow and 3 g/large burrow.

### HARVESTING AND THRESHING

Yellow and dry straw is an important visual indicator for readiness to harvest wheat crop. Shredding, breaking of spikes and shattering of grains are common if the standing crop is allowed to over ripe. The most suitable stage for harvesting wheat is when grains become hard and contain 20-25% moisture. Harvesting is generally done manually with serrate edged sickles. Bullock-driven reapers are also used occasionally. Combines are used by big farmers to do harvesting, threshing and winnowing wheat in a single operation. Custom use of combines is getting popular due to shortage of labour. Wheat crop harvested manually or by reapers is dried for three to four days on the threshing floor and then threshing is done by power-driven stationary threshers.

### QUALITY

The physical and nutritional aspects of wheat grain determine its quality. Purity, moisture content, appearance (colour, size and plumpness) and hardness of kernel decide the physical quality of wheat grain. Purity of grains is determined by calculating the percentage of pure wheat grains in a bulk sample.



The moisture content of wheat grain is important from the milling and storage view point. The optimum moisture content in the grain is about 12%. Grains which are large, plumed and amber in colour are considered better. The hardness is determined by the Pearling Index. A higher value of the Pearling Index indicates less kernel hardness. The Pearling Index is determined as:

$$\text{Pearling Index} = \frac{x - y}{x} \times 100$$

where  $x$ , initial sample weight, sample is generally 20 grains;  $y$ , weight of the material left on a 30 mesh sieve.

The nutritional aspect of wheat grain is determined by chemical analysis of wheat grains. Normally wheat grain contains 60-68% starch, 8-15% protein, 1.5-2.0% fat, 2.0-2.5% cellulose and 1.5-2.0% minerals. Higher values of above-mentioned parameters are desirable.

Milling quality, *chapati*-making quality, bread-making quality and biscuit-making quality are also important from the industrial and consumers point of view. The milling quality is judged by the following standards.

- (i) The maximum yield of flour free from germ and bran.
- (ii) The relative ease with which a high turnover of flour is obtained.
- (iii) The low ash content indicating a thorough separation of bran from flour.

*Chapati*-making qualities comprise water absorption, dough colour, dough properties (mixing and handling), puffing, texture, preservation quality, taste and aroma. Bread-making quality is determined by high water absorption, gas-production capacity and gas-retention capacity. Soft and weak flour of wheat having low water-absorption capacity of high protein content is considered ideal for biscuit making. Gluten should have plasticity so that the flour can be stretched without much shrinkage.

An ideal durum wheat for macaroni products should have excellent grain qualities like bold and plump grains, low yellow berry, high carotene content, high semolina yield and excellent quality for making vermicelli. Popular varieties of wheat are classified based on their specific product quality are given in Table 2.16.

**Table 2.16** Promising genotypes for specific end product quality

Quality product	Promising genotypes
<i>Chapati</i> (Score < 8.0/10)	C 306, LOK 1, SUJATA, RAJ 3765, HD 2285, PBW 373, PBW 533, HUW 234, K 9107, MACS 6145, MACS 6164, NW 1014, HI 1500, UP 262, HW 2004, DL 788-2, GW 273, GW 322, HD 2833, GW 173 and DBW 39.
Bread (>575 ml bread loaf volume)	HI 977, HS 240, VL 738, HD 2285, HD 2733, LOK 1, GW 120, GW 173, GW 190, HD 2189, MACS 2496, NI 5439, K 9107, HD 2733, NIAW 917 and DBW 39.
Biscuit (>7.5 biscuit spread factor)	Sonalika, UP 2425, WH 542, HD 2687, Raj 3765, PBW 373, DBW 16 and DBW 39.
Pasta	PDW 233, WH 896, HI 8498, HD 4672, RAJ 1555, A 9-30-1, MACS 2846, DDK 1009 and NP 200



## POST-HARVEST TECHNOLOGY

### Seed storage

Seed storage is required for consumption in subsequent months and seeds for next sowing. Seed can be stored in metallic drums, polythene bags and earthen pots. The critical moisture content of wheat seeds at which the rate of respiration increases is 14.6%. Seeds containing higher moisture respire faster, depleting seeds food reserve (Clements, 1988). The monsoon climate is ideally suited for insect proliferation. The major storage pests are rice weevil (*Sitophilus oryzae*), grain moth (*Rhizopertha dominica*) and the Khapra beetle (*Trogoderma gravesium*). *Aspergillus* and *Penicillium* can also damage wheat grains stored in moist conditions.

### Milling

Dried grains are first cracked or crushed gradually, through a series of chilled iron break-rolls. These are then passed through reduction rolls, wherein finer and whiter fractions are combined into patent flour (commercial flour). The remaining darker grades are marketed for special baking. Bleaching is done to remove xanthophyll pigments. Benzoyl peroxide or nitrogen trichloride in small quantities has bleaching effects, but higher doses are detrimental. Flour yields from milling are approximately 70 to 74% (Martin and Leonard, 1950).

## SUMMARY

- Origin of the durum wheat was probably in the region of Abyssinia, whereas the soft wheats originated in the region of West Pakistan, Western Afghanistan and southern parts of mountainous Babshara.
- Wheat is world's number two crop and in 2009 it was grown on 226 million ha. The world production of wheat in 2009 was 686 million tonnes.
- China is ahead of all countries, while India is second in order in production. UK leads in productivity (7.92 tonnes/ha).
- In India while Uttar Pradesh leads in area and total production, Punjab leads in productivity.
- There are 3 distinct groups of wheat. Bread wheat (*T. aestivum*) is grown all over the country, while durum wheat (*T. durum*) is mostly grown in central India and emmer wheat (*T. diococcum*) is grown in southern hill region.
- Wheat needs light preparation of land. It does well even with zero tillage after rice.
- Proper selection of variety as per recommendation for different agro-climatic zones and for different times of sowing makes a lot of difference in final yield.
- Use of seed drill or fertilizer-cum-seed drill helps in attaining the potential yield of variety.
- Balanced fertilization is the key for higher yield of wheat. Half dose of nitrogen, full dose of phosphorus and potassium should be applied at the time of sowing and remaining half dose should be top-dressed at first irrigation in medium and heavy soils and in two splits, at first and second irrigation on sandy soils. On calcareous and strongly alkaline soils, nitrogen



should be incorporated in upper layer of soil. Mixing of rockphosphate with pyrites increases the efficiency of rock phosphate.

- Wheat requires 4-6 irrigations. The critical growth stages are crown-root initiation (CRI), late tillering, late joining, flowering, milk and dough stage.
- Adoption of rice-wheat cropping system has created problem of *Phalaris minor* and *Avena fatua*. Both the weeds can be controlled by post-emergence application of isoproturon at 1-1.5 kg a.i. or methabenzthiazuron or metoxuron at 1.5 kg a.i. in 700-800 litres of water within 30-35 days after sowing.
- For overcoming the problem of rusts and loose smut only resistant varieties should be grown.

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## Maize

A.R. Sharma and Anchal Dass

Maize (*Zea mays* L.) is one of the most versatile crops grown throughout the tropical as well as temperate regions of the world. A crop of maize is sown and harvested somewhere in the world in every month of the year. It is grown from 60°N in Canada and Russia to 40°S latitude in Argentina, from below sea-level to an altitude of > 4,000 m in the Peruvian Andes, and in regions with < 25 cm rainfall in semi-arid plains of Russia to regions of > 1,000 cm rainfall in north-east India. Modern archeological and genetic studies reveal that teosinte (*Euchlaena mexicana* Schrad.), the closest wild relative of maize, was first domesticated in southern Mexico around 4,000 to 3,000 BC (Mengelsdraf *et al.*, 1964; Mengelsdraf, 1974). Greatest genetic diversity of maize is available in South American continent, and the centres of origin are, Peru, Bolivia and Ecuador (De Wit *et al.*, 1972). During 1,400 BC, maize cultivation started in both Mexican coasts. Native Americans classified the major lineages of maize, viz. dent, flint, flour, pop and sweet corn. The American Indians treated it as cereal and started eating it. The name 'corn' is derived from Indo-European word, which means 'small nugget'. When English and German settlers arrived in the new world, they referred maize as 'corn'. They distinguished it from other grains by calling it 'Indian corn'. The origin of the word 'maize' is believed to be from Taino people in Northern Antilles island (near present day San Salvador). The word 'Taino' means *mahis*, which was considered as source of life. Over the time, the *mahis* word transmuted into maize. After domestication, maize spread fairly quickly through North and South America, reaching the north-eastern USA and southern Canada prior to European colonization. It spread rapidly throughout Europe, and from Europe, to other parts of the world after the discovery of Americas. It is believed to have been introduced into Asia from same part of America (Tollenaar and Dwyer, 1999).

De Condolle (1886) assumed that corn must have originated in New Granada, now Colombia. Reeves (1944) postulated that maize had its origin in the lowlands of South America primarily because of historical references to pod corn in that area. It is now considered that corn had perhaps more than one origin. Several workers say it originated in both Mexico and South America.



There have been four principal theories regarding the origin of maize:

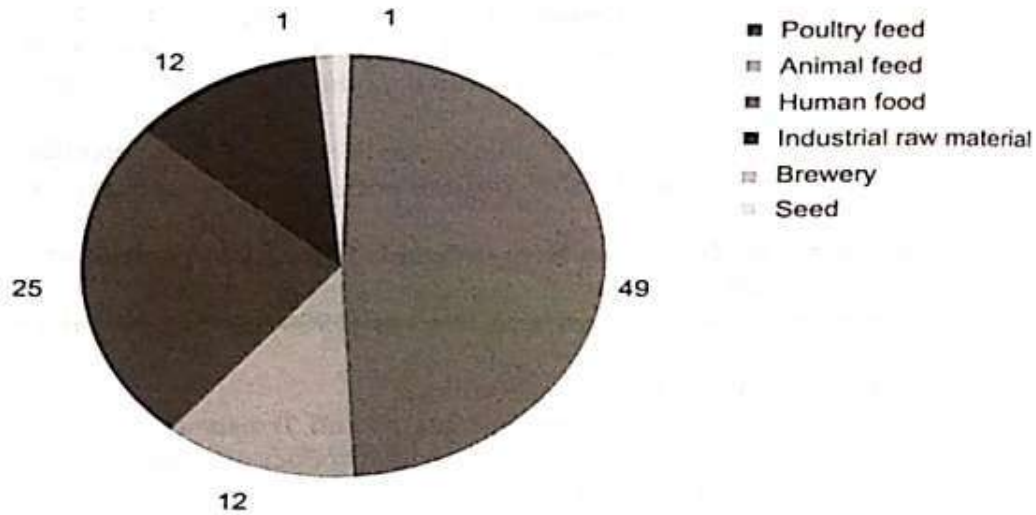
- that cultivated maize originated from pod corn, a form in which the individual kernels are enclosed in floral bracts as they are in other cereals and in the majority of grasses
- that maize originated from its closest relative, teosinte, by direct selection, by mutation, or by the hybridization of teosinte with an unknown grass now extinct
- that maize, teosinte, and *Tripsacum* have descended along independent lines directly from a common ancestor
- the tripartite theory of Mangelsdorf and Reeves (1939), which postulates that:
  - (a) cultivated maize originated from pod corn,
  - (b) teosinte is a derivative of a hybrid of maize and *Tripsacum*,
  - (c) the majority of modern corn varieties are the product of admixture with teosinte or *Tripsacum* or both.

Several discoveries have aroused the possibility either of an Asiatic origin of maize or of its pre-Colombian diffusion to that part of the world. One of these is a report of variety of maize with primitive characteristics being grown in Sikkim (Dhawan, 1964). This maize called as 'Sikkim Primitive' attains a height of 130 - 200 cm and each plant has 2 - 4 tillers. Each main stalk/tiller bears 4 - 6 ears and is terminated by a drooping tassel. The kernels are small, round and hard, and pop when heated. It seems to be related to the Mexican popcorn race Palomero Toluqueno.

Maize is used as a staple human food, livestock and poultry feed, and for fermentation and many industrial purposes. In the USA, 75% of the starch produced by wet milling is used in hydrolyzed products, mainly sweeteners; and the rest as industrial starch. Various alcoholic beverages and industrial products are produced by maize distillery and fermentation industries. The fermentation of maize starches and sweeteners has made it an important feedstock for ethanol (ethyl alcohol), which is being used as a bio-fuel; a mixture of 10% ethanol and 90% gasoline is called 'gasohol'. In India, maize is milled largely by the dry milling process, both for producing the flour, and livestock and poultry feed. About 85% of the maize produced is consumed as human food and animal feed including poultry (Fig. 3.1). Industrial use of maize is limited at present. However, there exists a scope for using maize as a basic raw material to several industrial products, such as starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries. With the advent of biotechnology, it has been suggested that maize hybrids will be developed for specific industrial uses by changing the chemical composition of the kernel.

#### AREA, PRODUCTION AND PRODUCTIVITY

Globally, maize is cultivated on 159 million ha (M ha) in more than 150 countries, having wide variations in soil, climate, biodiversity and management practices. The total production of maize in the world is 819 million tonnes (M t), with a yield of 5.2 tonnes/ha. More than 40% of the maize grain is produced



**Fig. 3.1** Consumption pattern of maize grain in India (*Source: DMR, 2011*)

in the USA, followed by China (20.0%), Brazil (6.3%), Mexico (2.5%), Indonesia (2.2%) and India (2.0%). The USA also has the highest yield (10.3 tonnes/ha), which is twice more than the world's average. Area, production and yield in major maize-growing countries of the world are given in Table 3.1.

In India, maize is the third most important cereal crop after rice and wheat. It is cultivated on 8.3 million ha under a wide range of agro-ecological situations. The total production of maize grain crossed 21 million tonnes, with

**Table 3.1** Maize statistics in major countries of the world during 2009

Country	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)	Contribution to world production (%)
USA	32.21	333.01	10.34	40.67
China	31.20	164.11	5.26	20.04
Brazil	13.79	51.23	3.71	6.26
Mexico	6.22	20.14	3.24	2.46
Indonesia	4.16	17.63	4.24	2.15
India	8.33	16.68	2.00	2.04
France	1.68	15.29	9.10	1.87
Argentina	2.34	13.12	5.61	1.60
South Africa	2.43	12.05	4.97	1.47
Ukraine	2.09	10.49	5.02	1.28
Canada	1.14	9.56	8.37	1.17
Romania	2.34	7.97	3.42	0.97
Philippines	2.68	7.03	2.62	0.86
Rest	48.02	140.51	2.93	17.16
World	158.63	818.82	5.16	100.00

*Source: Agricultural Statistics at a Glance (2011)*



**Table 3.2** Area, production and yield of maize in different states of India during 2010-11

State	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)
Karnataka	1.25 (106.5)	4.36 (165.9)	3.50 (28.1)
Andhra Pradesh	0.79 (68.6)	4.17 (182.5)	5.30 (66.2)
Maharashtra	0.80 (168.4)	2.27 (340.8)	2.85 (67.6)
Rajasthan	1.10 (13.4)	2.02 (87.6)	1.83 (65.9)
Bihar	0.64 (-2.8)	1.43 (-3.5)	2.26 (-1.3)
Uttar Pradesh	0.71 (-21.7)	1.08 (-13.4)	1.51 (10.8)
Madhya Pradesh	0.84 (-3.1)	1.08 (-23.1)	1.30 (-20.7)
Himachal Pradesh	0.30 (-1.5)	0.69 (15.0)	2.32 (16.6)
Tamil Nadu	0.25 (173.6)	1.08 (649.0)	4.41 (173.4)
Gujarat	0.50 (19.4)	0.76 (19.2)	1.51 (1.5)
Jammu and Kashmir	0.31 (-3.2)	0.55 (7.7)	1.75 (11.3)
Punjab	0.14 (-12.6)	0.53 (32.1)	3.77 (51.8)
West Bengal	0.09 (152.6)	0.39 (362.8)	4.30 (81.8)
Jharkhand	0.16 (35.0)	0.20 (8.5)	1.25 (-18.0)
Others	0.44 (33.6)	0.67 (40.4)	1.54 (-2.1)
Total	8.30 (27.9)	21.28 (80.3)	2.56 (41.0)

Figures in parentheses indicate per cent change over the mean values for the period from 1998-99 to 2002-03

Source: *Agricultural Statistics at a Glance, 2011*

an average yield of 2.5 tonnes/ha during 2010-11 (Table 3.2). However, this yield is about half of the world's average and one-fourth of that in the USA. This is because of cultivation of maize largely under rainfed conditions (75% area), low spread of high-yielding varieties/hybrids (60%), and various biotic and abiotic stresses. About 85% of the crop area is in the spring, summer and *kharif* seasons, and 15% in the *rabi* (winter) season, the latter mainly in Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra, Bihar and West Bengal. The major growing states contributing > 85% of the total maize production are: Karnataka (20.5%), Andhra Pradesh (19.6%), Maharashtra (10.7%), Rajasthan (9.5%), Bihar (6.7%), Uttar Pradesh (5.1%), Madhya Pradesh (5.1%), Tamil Nadu (5.1%) and Himachal Pradesh (3.2%). There have been significant changes in maize cultivation in different states of India during the last decade, with some states like Karnataka, Maharashtra, Tamil Nadu and West Bengal registering > 100% increase in area and production; while others like Bihar, Uttar Pradesh and Madhya Pradesh are showing negative growth.

Unlike other cereal crops, maize has shown impressive trends in growth rate in terms of area, production and yield during the last two decades (Fig. 3.2). This has been owing to its expansion in non-traditional areas, particularly during the winter season, and introduction of single-cross hybrids. Maize has emerged as an important crop in the non-traditional states like Andhra Pradesh, Tamil Nadu, Karnataka and West Bengal, which have shown the largest increase in area, production and productivity during the winter season (Fig. 3.3). On the other hand, the states such as Bihar, Uttar Pradesh and Madhya Pradesh

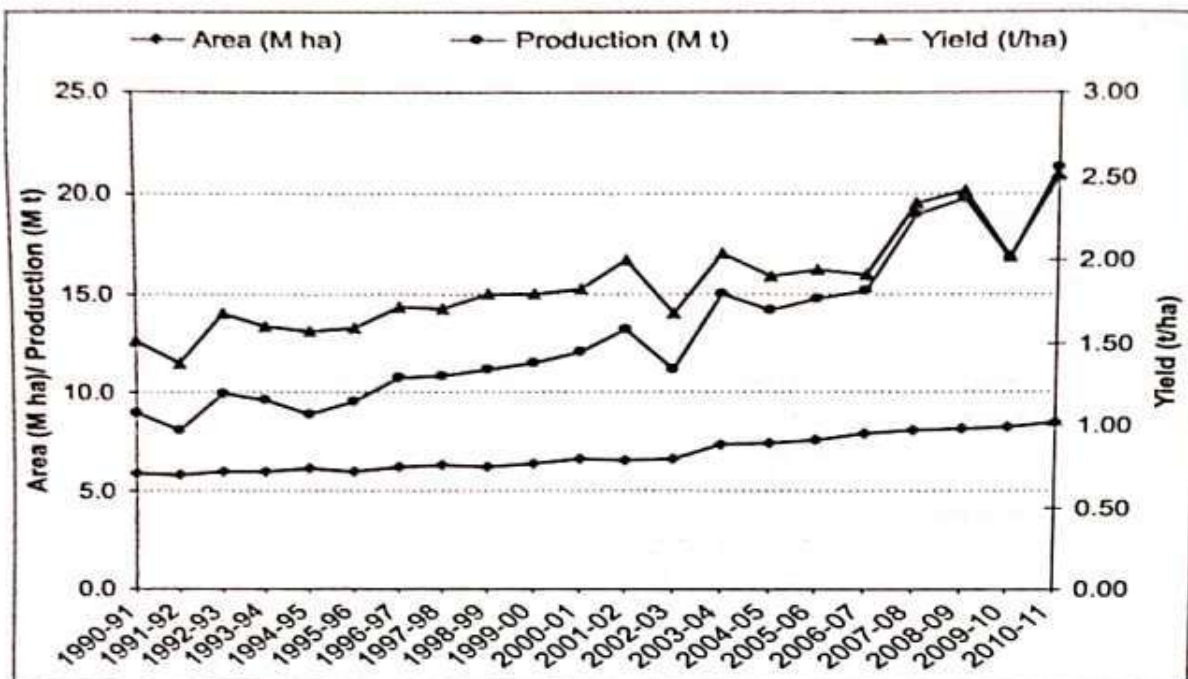


Fig. 3.2. Trends in area, production and yield of maize during the last two decades in India (Source: *Agricultural Statistics at a Glance, 2011*)

have registered negative trends in growth of area and production. The highest yields of maize are in Andhra Pradesh, followed by Tamil Nadu, West Bengal, Punjab and Karnataka.

### TAXONOMY AND CLASSIFICATION

Maize is an annual plant belonging to the tribe Tripsaceae (Maydeae) of grass family (Gramineae or Poaceae). The tribe consists of 8 genera, and the genus *Zea* is represented by a single species, *mays*, which is of great economic importance. *Zea mays* is further classified into different groups as:

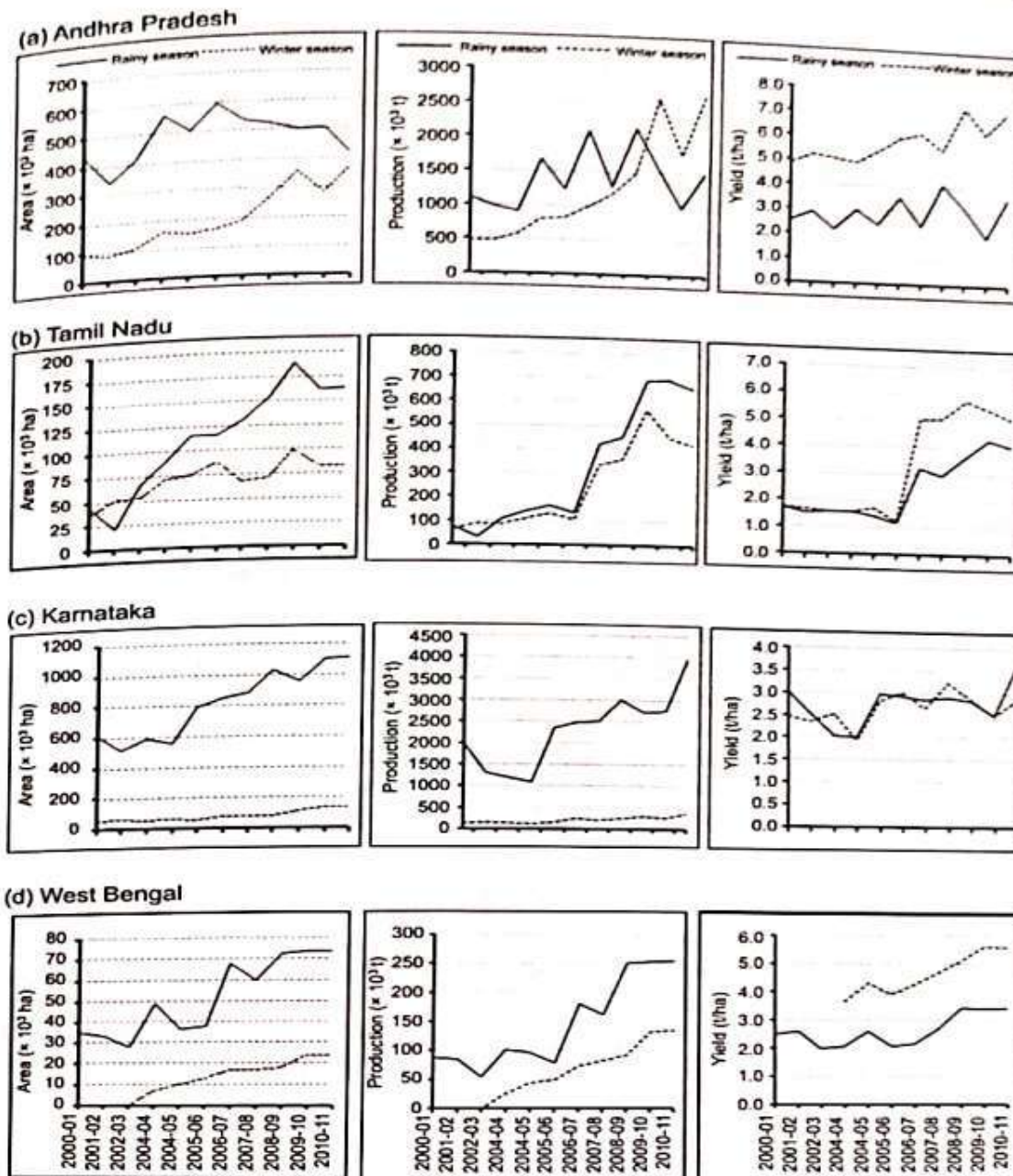
#### Flint maize (*Zea mays indurata*)

The entire outer portion of the kernel is composed of 'hard' starch, i.e. amylopectin, which restricts easy absorption of moisture and avoids spoilage. Flint maize matures early and its germination is better in cold and wet soil. Flints come in many colours – white, yellow, red-blue or their variable.

#### Dent maize (*Zea mays indentata*)

It accounts for 95% of all maize grown in the USA. The hard starch is confined to the sides of the kernel. The amylose of 'soft' starch which forms the core and cap, contracts when the grain is dried, producing the characteristic dent in the top of the kernel. It is used for livestock feeding. It may be yellow, white or red.





**Fig. 3.3.** Season-wise trends in area, production and yield of maize in selected states (Source: Agricultural Statistics at a Glance, 2011)

**Sweet corn (*Zea mays saccharata*)**

It is grown primarily as a food, and is harvested with about 70% moisture before hardening and drying of the grain starts. It is mainly grown in the USA and Canada. Yellow is the predominant grain colour. Sweet corn is a good

source of energy. About 20% of the dry matter is sugar, compared with only 3% in dent maize at green ear stage. It is also a good source of vitamin C and A.

**Flour maize (*Zea mays amylacea*)**

It is grown in the Andean Highlands of South America and drier areas of south-west USA. The kernels of flour maize are composed largely of soft starch with little or no hard starch. It is preferred by the earlier native populations because the kernels were easy to grind and make flour.

**Pop corn (*Zea mays everta*)**

It is a popular snack food in many parts of the world. Its kernels are small and it is an extreme form of flint maize. When heated to about 170°C, the grains swell and burst, turning inside out. At this temperature, water held in the starch of the kernel tissue turns to steam and the pressure causes the endosperm to explode.

**Pod corn (*Zea mays tunicata*)**

The crop is not grown commercially. Each kernel is enclosed in pod or husk in an ear, which is enclosed in husks like other types of corn.

**Waxy maize (*Zea mays ceratina*)**

It is named for the, somewhat, waxy appearance of the kernels. China was the original source of the waxy gene (WX). Waxy maize starch is composed entirely of amylopectin, in contrast with common dent maize starch, which is approximately 78% amylopectin and 22% amylose. Waxy maize hybrids have been developed and are being grown to supply raw materials for speciality products of the wet milling starch industry for textile, paper sizing and corn oil.

### VARIETAL DEVELOPMENT

Maize is a cross-pollinated crop, and the cultivars grown in India comprise varieties, hybrids, composites and synthetics. Hybridization is the most potent technique for improving the yield potential of maize, and heterosis vigour has been exploited extensively. Composite varieties are produced by mixing the seed of several photosynthetically outstanding lines and encouraging open pollination to produce crosses in all combinations. Synthetics are produced by crossing a number of lines that combine well with each other, and once synthesized, these are maintained by open pollination in isolation. Unlike hybrids, the seed of composites and synthetics can be used year after year maintaining the production potential undiminished, whereas the hybrids give 15-20% less yield than the  $F_1$  generation seed in the following years. In India, the high-yielding varieties and hybrids of maize occupy 60% of the total area, compared with 85% in wheat and 74% in rice (Joshi *et al.*, 2005).

Selection of varieties and hybrids suited to a particular agro-ecological condition, maturity, season and purpose is the key for getting potential productivity of this crop. It is always better to select single-cross hybrids



developed and released for a set of climatic conditions. The single-cross hybrids also perform better under the stressed environments. However, in areas where hybrid seed availability cannot be ensured like high altitude and tribal regions, high-yielding composite varieties can also be grown. Several hybrids and composite varieties of different maturity groups for various purposes have been developed and released in different states of India. Hybrids and composites of different maturity groups for *kharif* (Table 3.3), *rabi* (Table 3.4) and spring season (Table 3.5) are given in respective tables.

### THE PLANT

Maize is a tall plant with a fibrous root system. It has a single leaf at each node, and two successive leaves along the stem of maize have an approximately opposite azimuthal orientation. Number of leaves per plant varies from 7 for the short-season open-pollinated variety 'Gaspe Flint' to more than 30 for tropical cultivars; the leaf number for temperate climate maize hybrids ranges from 16 to 23. Maize is monoecious, with staminate flowers on the terminal branched end of a tall erect stem (the tassel) and pistillate flowers on the axillary shoots (ear shoots).

#### Root

The root system of maize as in other herbaceous monocotyledons is composed of several distinctive types of roots, mainly (i) the seminal roots, (ii) the primary or tap root or radicle, and (iii) the associated lateral roots. The seminal roots are present in the ungerminated seed and remain functional during the initial phase. The shoot-borne roots that originate at the nodes on lower portion of the germinated seedling, i.e. on the basal nodes of the stem below the soil level, are called adventitious roots, while the shoot-borne roots that are formed at the nodes on portions of the stem above the soil level (mostly at the lower-most 2-3 nodes) are usually referred to as prop or brace roots (Feldman, 1994).

Both the seminal and tap roots are important during early seedling development but the former assume less importance and frequently decay following development of the permanent adventitious root system. Permanent adventitious roots originate from nodes and the below-ground portion of the stem. The prop or brace roots formed in the lowermost 2-3 nodes of the above-ground portion of the stem help in keeping the plant upright or in preventing a plant from lodging completely.

#### Leaf

Each leaf is divided into the basal portion, called the sheath and the distal or tip portion, called the blade. At the boundary between sheath and blade is the ligular region, consisting of a pair of wedge-shaped, light green auricles and the unique epidermal line of apparently fused hairs, the ligules. The auricles begin as points at the mid-vein and get larger towards the margins of the leaf (Freeling and Walbot, 1994). Sylvester (1990) and Poethig (1990) reported that wax production varied with location of the leaves; the leaf (L) 4 was entirely

**Table 3.3** Maize varieties/hybrids of different maturity suitable for various states during rainy season

State	Extra early maturity	Early maturity	Medium maturity	Late maturity
Delhi	H:Vivek 17, Vivek 21, PMH 2	H:PAU 352, PEHM 3, Parkash, X 3342, JH 3459, PEHM 2	H:HM 4, HM 8, HM 10, DK 701, KMH 3712, PMH 4	H: HM 11, PMH 3, Buland, NK 61, Pro 311, Bio 9681, Seed Tech 2324
Punjab	H:Vivek 17, Vivek 21, PEEHM 5	H:PAU 352, PEH 3, JH 3459, Parkash, PMH 2, X 3342	H:HM 4, HM 8, HM 10, DK 701, KMH 3712, PMH 4	H: HM 11, PMH 3, PMH 1, Buland, Pro 311, Bio 9681, NK 61, Pro 311, Seed Tech 2324
Haryana	H:Vivek 17, Vivek 21, PMH 2, PEEHM 5	H:PAU 352, PEHM 3, JH 3459, Parkash, X 3342	H:HHM 1, H:HM 2, HM 4, HM 5, HM 8, HM 10, DK 701, KMH 3712, PMH 4	H: HM 11, PMH 3, Buland, HM 5, NK 61, Pro 311, Bio 9681, Seed Tech 2324, HHM 1
Uttar Pradesh	H:Vivek 5, HM 15, HM 17, HM 21, HM 27, PMH 2	H: JH 3459, Parkash, PEHM 2, X 3342 C: Pusa Composite 4	H:HM 8, HM 10, Malviya Hybrid Makka 2, Bio 9637, DK 701, KMH 3712, PMH 4	H: HM 11, PMH 3, Buland, Pro Agro 4212, Pro 311, Bio 9681, NK 61, Seed Tech 2324, MCH 38, Mon 29
Rajasthan	H:Pratap Hybrid 1, Vivek 4, Vivek 17	H: PEHM 2, Parkash, Pro 368, X 3342 C: Pratap Makka 3, Aravali Makka 1, Jawahar Makka 8, Amar, Azad Kamal, Pant Sankul Makka 3, PMH 5	H: HM 10, NK 21 C: Pratap Makka 5, X7B 401, KMH 3712, Bisco 111	H: HM 11, Trishulata, Pro 311, Bio 9681, Seed Tech 2324
Madhya Pradesh	H:Pratap Hybrid 1, Vivek 4, Vivek 17	H: PEHM 2, Parkash, Pro 368, X 3342 C: Jawahar Makka 8, Jawahar Composite 12, Amar, Azad Kamal, Pant Sankul Makka 3, Chandramani, Pratap Makka 3, PMH 5	H: HM 10, NK 21 C: Pratap Makka 5, X7B 401, KMH 3712, Bisco 111	H: HM 11, Trishulata, Pro 311, Bio 9681, Seed Tech 2324
Gujarat	H:Pratap Hybrid 1, Vivek 4, Vivek 17	H: PEHM 2, Parkash, Pro 368, X 3342 C: Jawahar Makka 8, Pant Sankul Makka 3, Pratap	H: HM 10, NK 21 C: Pratap Makka 5, X7B 401, KMH 3712, Bisco 111	H: HM 11, Trishulata, Pro 311, Bio 9681, Seed Tech 2324 C: GM 3

Table 3.3 contd



Table 3.3 contd

State	Extra early maturity	Early maturity	Medium maturity	Late maturity
		Makka 3, GM 2, GM 4, GM 6, Aravali Makka 1, Narmada Moti, PMH 5		
Andhra Pradesh	H:Vivek 9, Vivek 15, Vivek 17, Vivek 21, Vivek 27, PEEHM 5	H:PEHM 1, PEHM 2, DHM 1, BH 2187, Parkash, JKMH 1701, X 3342	DHM 111, DHM 117, DHM 113, HM 8, HM 10, MCH 37, DHM 119, Bisco 855	H: HM 11, DHM 113, Kargil 900 M, Seed Tech 2324, Pro 311, Bio 9681, Pioneer 30 V 92, Prabal, Pioneer V 92, MCH 38
Tamil Nadu	H:Vivek 9, Vivek 15, Vivek 17, Vivek 21, Vivek 27, PEEHM 5	H:PEHM 2, Parkash, X 3342 JKMH 1701	HM 8, HM 10, COHM 4, MCH 37, DHM 119, Bisco 855	H: HM 11, COHM 5, Prabal, Pro 311, Bio 9681, Seed Tech 2324, Pioneer 30 V 92, MCH 38
Maharashtra	H:Vivek 9, Vivek 15, Vivek 17, Vivek 21, Vivek 27, PEEHM 5	H: PEHM 1, PEHM 2, Parkash, X 3342, JKMH 1701	HM 8, HM 10, MCH 37, DHM 119, Bisco 855	H: HM 11, Prabal, Pro 311, Bio 9681, Seed Tech 2324, Pioneer 30 V 92, MCH 38, Shatak 9905
Karnataka	H:Vivek 9, Vivek 15, Vivek 17, Vivek 21, Vivek 27, PEEHM 5	H: PEHM 2, Parkash, X 3342 JKMH 1701 C: NAC 6002	HM 8, HM 10, MCH 37, DHM 119, Bisco 855	H: HM 11, EH 434042, H:Nithya Shree, EH 434042, DMH 1, DMH 2, Bio 9681, Prabal, Pro 311, Seed Tech 2324 C: NAC 6004, Pioneer 30 V 92, MCH 38, H: HM 11
Jammu and Kashmir	H: Vivek 15, Vivek 21, Vivek 25, Vivek 33, PEEHM 5 C: Pratap Kanchan 2, Shalimar KG 1, Shalimar KG 2, Vivek 35, Vivek 37	H: Vivek 33, Parkash, JKMH 1701, X 3342 C: C 8, C 14, C 15	H: HM 10 C: C 6	H: HM 11
Uttara-	H: Vivek 5, Vivek 9,	Vivek 33, Vivek 23,	H: HM 10	H: HM 11

Maize

Table 3.3 contd

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Table 3.3 concluded

State	Extra early maturity	Early maturity	Medium maturity	Late maturity
khand	Vivek 21, Vivek 25 PEEHM 5 C: Pratap Kanchan 2, Vivek 35, Vivek 37	Parkash	C: Bajaura Makka, PMH 4	
Bihar	H: Vivek 27 C: D 994	H: Parkash, X 3342 C: Dewaki, Birsa Vikas Makka 2	HM 9, Malviya Hybrid Makka 2, KMH 3712	H: HM 11, Pro 311, Bio 9681, Seed Tech 2324, Pioneer 30 V 92, 900 M C: Hemant, Suwan, Lakshmi, MCH 38, Mon 29
Jhar- khand	H: Vivek 27 C: D 994	H: Parkash, X 3342 C: Dewaki, BVM 2, BM 1	HM 9, Malviya Hybrid Makka 2, DK 701, KMH 3712	H: HM 11, Pro 311, Bio 9681, Seed Tech 2324 C: Suwan, MCH 38, Mon 29
Odisha	H: Vivek 27 C: D 994	H: Parkash, HIM 129, X 3342	HM 9, Malviya Hybrid Makka 2, DK 701, DMH 115, Pro 345, KMH 3712	H: HM 11, Pro 311, Bio 9681, Seed Tech 2324, PAC 705, MCH 38, Mon 29
West Bengal	H: Vivek 27	H: Parkash, X 3342	H: Malviya Hybrid Makka 2, KMH 3712	H: HM 11, Pro 311, Bio 9681, Seed Tech 2324
Himachal Pradesh	H: Vivek 15, Vivek 21, Vivek 25, PEEHM 5	H: Parkash, X 3342	C: Bajaura Makka, Pratap Makka 4	H: HM 11, Pro 311, Bio 9681, Seed Tech 2324
NEH Region	H: Vivek 21, Vivek 25, PEEHM 5	H: Parkash, JKMH 1701, X3342	C: Pratap Makka 4	H: HM 11, Pro 311, Bio 9681, Seed Tech 2324 C: NLD White
Chhattis- garh	H: Vivek 27	H: Parkash, X 3342, PMH 5	C: Pratap Makka 5, X 7B 401, KMH 3712, Bisco 111	H: HM 11, PEHM 1, Pioneer 30 V 92 Pioneer 30 R 26, Bio 9681, Pro 4640, Pro 4642
Asom	H: PEEHM 5	H: Parkash, X 3342	H: DK 701 C: Pratap Makka 4	H: HM 11, C: Vijay, NLD White

C, Composite; H, hybrid



**Table 3.4** Maize varieties/hybrids of different maturity suitable for various states during winter season

State	Late maturity
Delhi	H: PMH 3, Buland, NK 61, Pro 311, Bio 9681, Seed Tech 2324, HM11, HM 8
Punjab	H: PMH 3, PMH 1, Buland, Sheetal, Pro 311, Bio 9681, NK 61, Pro 311, Bio 9681, Seed Tech 2324, HM11, HM 8
Haryana	H: PMH 3, Buland, HM 5, NK 61, Pro 311, Bio 9681, Seed Tech 2324, HM 11, HM 2, HM 1, HM 8
Uttar Pradesh	H: PMH 3, Buland, Pro Agro 4212, Pro 311, Bio 9681, NK 61, Seed Tech 2324, HM 8
Rajasthan	H: Pro 311, Bio 9681, Seed Tech 2324, HM 8
Madhya Pradesh	H: Pro 311, Bio 9681, Seed Tech 2324
Gujarat	H: Pro 311, Bio 9681, Seed Tech 2324 C: GM 3, Ganga Safed 2
Andhra Pradesh	H: Kargil 900 M, Seed Tech 2324, Pro 311, Bio 9681, Poineer 30 V 92, Prabal, 900 M
Tamil Nadu	H: COHM 5, Prabal, Pro 311, Bio 9681, Seed Tech 2324, Poineer 30 V 92, 900 M
Maharashtra	H: Prabal, Pro 311, Bio 9681, Seed Tech 2324, Poineer 30 V 92, 900 M
Karnataka	H: Nithya Shree, DMH 1, DMH 2, 900 M, Bio 9681, Prabal, Pro 311, Bio 9681, Seed Tech 2324 C: NAC 6004, 30 V 92
Bihar	H: Rajendra Hybrid 2, Rajendra Hybrid 1, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 M C: Hemant, Suwan, Lakshmi
Jharkhand	H: Pro 311, Bio 9681, Seed Tech 2324 C: Suwan
Odisha	H: Pro 311, Bio 9681, Seed Tech 2324, PAC 705
West Bengal	H: Pro 311, Bio 9681, Seed Tech 2324
Himachal Pradesh	H: Pro 311, Bio 9681, Seed Tech 2324
NEH Region	H: Pro 311, Bio 9681, Seed Tech 2324 C: NLD White
Chhattisgarh	H: PEHM 1, Pioneer 30 V 92, Poineer 30 R 26, Bio 9681, Pro 4640 and 4643, 900 M
Asom	C: NLD White

C, composite; H, hybrid

**Table 3.5** Maize varieties/hybrids of different maturity suitable for various states during spring season

State	Extra early maturity	Early maturity
Delhi	H: Vivek 17, Vivek 21, PMH 2	H: PAU 352, PEHM 3, Parkash, X 3342
Punjab	H: Vivek 17, Vivek 21, PEEHM 5	H: PAU 352, PEHM 3, JH 3459, Parkash, PMH 2, X 3342
Haryana	H: Vivek 17, Vivek 21, PMH 2, PEEHM 5	H: HHM 1, PAU 352, PEHM 3, JH 3459 Parkash, X 3342

Table 3.5 contd

Table 3.5 concluded

State	Extra early maturity	Early maturity
Uttar Pradesh	H: Vivek 5, Vivek 15, Vivek 17, Vivek 21, Vivek 27, PMH 2	H: JH 3459, Parkash, PEH 2, X 3342 C: Pusa Composite 4, Gaurav, Azad Uttam, Surya, Kiran, Tarun
Rajasthan	H: Pratap Hybrid 1, Vivek 4, Vivek 17	H: PEHM 2, Parkash, Pro 368, X 3342 C: Pratap Makka 3, Aravali Makka 1, Jawahar Makka 8, Amar, Azad Kamal, Pant Sankul Makka 3, Mahi Kanchan, Mahi Dhawal
Madhya Pradesh	H: Vivek 4, Vivek 17	H: PEHM 2, Parkash, Pro 368, X 3342 C: Jawahar Makka 8, Jawahar Composite 12, Amar, Azad Kamal, Pant Sankul Makka 3, Chandramani, Pratap Makka 3
Gujarat	H: Vivek 4, Vivek 17	H: PEHM 2, Parkash, Pro 368, X 3342 C: Jawahar Makka 8, Pant Sankul Makka 3, Pratap Makka 3, GM 2, GM 4 GM 6, Aravali Makka 1, Narmada Moti
Andhra Pradesh	H: Vivek 9, Vivek 15, Vivek 17, Vivek 27, PEEH 5	H: PEHM 1, PEHM 2, DHM 1, BH 2187, Parkash, JKMH 1701, X 3342
Tamil Nadu	H: Vivek 9, Vivek 15, Vivek 17, Vivek 21, Vivek 27, PEEHM 5	H: PEHM 2, Parkash, X 3342
Maharashtra	H: Vivek 9, Vivek 15, Vivek 17, Vivek 21 and Vivek 27, PEEHM 5	H: PEHM 1, PEHM 2, Parkash, X 3342, C: JKMH 1701
Karnataka	H: Vivek 9, Vivek 15, Vivek 21, Vivek 27, PEEHM 5	H: PEHM 2, Parkash, X 3342, C: NAC 6002
Jammu and Kashmir	H: Vivek 15, Vivek 21, Vivek 25, Vivek 33, PEEHM 5 C: Pratap Kanchan 2, Shalimar KG 1, KG 2	H: Vivek 33, Parkash, JKMH 1701, X 3342, C: C 8, C 14, C 15
Uttarakhand	H: Vivek 5, Vivek 9, Vivek 21, Vivek 25 PEEHM 5 C: Pratap Kanchan 2	H: Vivek Hybrid 33, Vivek Hybrid 23, Parkash
Bihar	H: Vivek 27 C: D 994, Gujarat Makai 6	H: Parkash, X 3342, C: Dewaki, Birsa Vikas Makka 2
Jharkhand	H: Vivek 27, C: D 994	H: Parkash, X 3342, C: Dewaki, BVM 2, BM 1
Odisha	H: Vivek 27, C: D 994	H: Parkash, HIM 129, X 3342
West Bengal	H: Vivek 27	H: Parkash, X 3342
Himachal Pradesh	H: Vivek 15, Vivek 21, Vivek 25, PEEHM 5	H: Parkash, X 3342
NEH Region	H: Vivek 21, Vivek 25, PEEHM 5	H: Parkash, JKMH 1701, X 3342
Chhattisgarh	H: Vivek 27	H: Parkash, X 3342
Asom	-	H: Parkash, X 3342

C, Composite; H, hybrid



covered with wax, L5 had the boundary near the base of the leaf, L6 near the middle, L7 near the tip, while L8 was entirely waxless.

### **Tassel**

The tassel is a branched inflorescence. It consists of a central spike (rachis) and about 10-50 lateral branches. The paired spikelets (pedicellate and sessile) occur in many ranks around the central spike. Each spikelet contains two florets. The development of upper floret is about 2-3 days ahead of the lower floret measured at anthesis. Each floret is enclosed with a pair of thin scales, a lemma (located adjacent to the glume) and a palea (located opposite to the lemma, between the two florets). Two of the three anthers present in each floret are located adjacent to the palea; the third is located adjacent to the lemma and is flanked by two lodicules. These lodicules swell at anthesis allowing extrusion of anthers by elongation of the filament. Following extrusion, anthers dangle downward and shed pollen from openings at the tip.

### **Ear**

The top one or several axillary buds terminate in an ear capable of producing mature kernels. Each of these axillary buds is covered with about 8-14 modified leaves called husks and a prophyll. The ear does not have lateral branches but its thick axis called the cob, is similar to the central spike of the tassel in that it produces multiple rows of paired spikelets (polystichous phyllotaxy) (Cheng and Pareddy, 1994).

### **Fertilization**

Each female flower contains a single ovary terminated by a long style, the pollen receptive organ, commonly known as silk. The silks are covered with fine hairs used to capture wind-blown pollen. The pollen which are produced at the tassel range 30 to 60 million per plant (Arber, 1934). Kiesselbach (1949) estimated in a Nebraska cornfield that on an average 42,500 pollengrains were produced for each square inch of the field. Pollen after falling on the silk start germinating and as a result pollen tubes are formed which penetrate the tissue of the silk. The pollen tubes reach the micropyles of the ovaries in 15-25 hr after pollination. The end of the tube ruptures, setting free the two sperms. One of these fuses with a female egg nucleus to produce embryo and the other fuses with a double nucleus to produce the endosperm—a food organ; used in seed germination. Fertilization of the two female nuclei by two male nuclei is known as double fertilization—a process characteristics of virtually all flowering plants. Thus, seed of corn is formed which remains alive for 3 to 5 years, and the maximum period of viability seldomly exceeds 10 years under ordinary storage conditions.

### **Life cycle**

Under optimum conditions of air, moisture and temperature, the seed absorbs water, swells and increases in weight. In 36-60 hr the primary root bursts through the pericarp; soon the plumule, i.e. the young stalk, surrounded



by a sheath, the coleoptile also bursts through the pericarp and begins to grow in the opposite direction. The next step is the appearance of several secondary rootlets at the base of the first root. These seedling roots comprise a temporary (seminal) root system supplying water and some nutrients until the permanent root system (adventitious roots) which grows from the lowest stalk joint, has developed. At this stage, most of the food utilized is from the endosperm.

The part of the young seedling between the seed and the lowermost joint of the stalk is known as the mesocotyl. The mesocotyle is a very delicate organ whose elongation is suddenly stopped when the tip of the coleoptile penetrates the surface of the soil and is exposed to light. For this reason, the first joint of the stalk from which the permanent root system later develops is always just below the surface of the soil regardless of the depth at which the seed is planted. Soon after the pointed coleoptile has emerged from the surface of the soil, the leaves begin to unfold and enlarge. Each leaf consists of the blade and the sheath which surrounds the stalk and is used by the plant for the food manufacture.

The permanent root system which develops at the lowest joint of the stalk is a fibrous, freely branching system which spreads out in all directions to a distance of 90-120 cm and may penetrate the soil in a depth of 120-260 cm. While the root system is developing, the leaves of the stalk, of which the lower ones are already well developed in the embryo, unfold one by one, alternating between opposite sides of the stalk. The leaf sheaths which surround the stalk also alternate in the way in which their margins overlap. In half of them, the left overlaps the right, while in the other half, the right margin overlaps the left.

With the unfolding of the uppermost leaf, the tassel makes its appearance. Soon after, it has completely emerged anthers, which begin to shed their pollen. At this very time, the silk emerges and pollination proceeds, the kernels swell, the ear shoot enlarges to become the mature ear and the cycle is completed. In majority of the varieties, the first silk is found to emerge from the lateral ear shoot about mid-way up the stalk; gradually proceeding upward and downward. Fertilization takes place at early two light hours when the humidity is the maximum and comes to an end within an hour or so of sunrise; daily covering just 8-12% of the cob length and whole process getting completed in about 7-10 days time, depending upon the cloud cover and rainfall during pollination period.

### GROWTH STAGES

Maize plants come in various sizes and shapes depending on their origin, relative maturity, specific end-use, and the environmental conditions under which they are grown. However, all maize plants go through the same phases of development from planting to maturity. The life cycle of maize can be divided into four distinct phases: (i) a period of predominantly vegetative growth (leaf growth phase), (ii) flowering period involving tassel emergence, anthesis, silking and fertilization of florets, (iii) grain-filling period during which the dry matter is allocated predominantly into the reproductive organs, and (iv) the final period of grain dry down during which no translocation occurs between the plant and the grain (Tollenar and Dwyer, 1999).



### CLIMATE

Maize is a versatile crop, and it is successfully grown in India under varied agro-ecologies, ranging from sea-level to high altitudes up to 3,000 m. It requires considerable moisture and warmth from germination to flowering. The most suitable temperature for germination is 21°C and for growth 32°C. Extreme high temperature and low humidity during flowering may damage the foliage, desiccate the pollen and interfere with proper pollination, resulting in poor grain filling. In India, it is cultivated in all the states, except Kerala. Maize is susceptible to frost, and damage to the winter crop is often noticed in parts of north-western India.

### SOILS

Maize can be grown successfully on a wide range of soils, ranging from loamy sand to clay loam. However, soils with good organic matter content, having high water-holding capacity with neutral to somewhat alkaline pH (7.5-8.5) are considered good for higher productivity. Being a sensitive crop to deficit moisture as well as excess water and salinity stress, it is desirable to avoid low-lying fields having poor drainage and also the fields having higher salinity.

### LAND PREPARATION AND SOWING

Maize crop needs well aerated, moist and weed-free land. To achieve such growing conditions, land preparation involves one deep ploughing in light-textured soils immediately after the previous winter/summer crop to ensure timely sowing of the crop. In case of heavy soils, 2-3 deep ploughing may be needed. The crop generally requires 2-4 harrowing each followed by planking. During *kharif* season, the crop needs protection from waterlogging, and shallow furrows should be provided after certain distance, which should connect to the main drain. The drains must be laid out across the slope, to control erosion caused by water. Sometimes, ridges and furrows are made in the entire field, particularly in high rainfall regions, and maize seeds are sown on the sides of the ridges. In *rabi* and spring seasons, crop is also sown in furrows for achieving greater water-use efficiency and higher yield.

#### Time of sowing

Maize is grown round the year in all seasons, viz. monsoon, post-monsoon, winter and spring, in different parts of the country. It is grown as an irrigated crop in the winter and spring seasons, but in the monsoon season it is mostly raised as a rainfed crop. For higher productivity of rainy-season irrigated crop, it is desirable to complete the sowing 15-20 days prior to the onset of monsoon. The early-sown crop gets established before the onset of south-west monsoon and tolerates better excess water stagnation. It also helps in vacating the field in time for sowing of catch crops like *toria* and potato in the north-western plains zone before taking a wheat crop. In rainfed areas, the sowing time normally coincides with the onset of monsoon.

The yield of winter maize is 1.5-2.0 times more than the rainy-season crop, although the duration of maturity also gets extended by about 50-60 days in north-western plains. Delay in sowing of winter maize beyond mid-November in north-western India results in poor germination and lower yield due to very cold conditions and frost damage during December-January, while in eastern and southern India, delayed sowing results in lower yields due to shortening of the growing season. In north-western India, the winter-season crop remains stunted in growth till the end of January. Sometimes, the leaves become pale yellow and may even partly dry but the growing point is not damaged. As soon as the season warms up, there is very quick recovery in growth.

Cultivation of maize is also possible in spring or in summer in north-western India (Kumar *et al.*, 2012). Spring crop can be sown from third week of January to mid-February, and the summer crop from the mid-March to end of April after wheat. The variety Punjab Sathi 1 is most suitable during summer because it is heat tolerant and matures in 70 days. The optimum time of sowing in different seasons in India is given in Table 3.6.

**Table 3.6** Optimum sowing time of maize in different regions of India

Region	Sowing time			
	<i>Kharif</i>	<i>Rabi</i>	Spring	Summer
North-western plains zone	May-end to early June (irrigated), last week of June to mid-July (rainfed), second fortnight of August (post-monsoon)	Last week of October for intercropping, and first fortnight of November for sole crop	Last week of January to mid-February	Mid-March to end of April
North-eastern hills	First week of March	Mid-October to mid-November		
North-western hills	April- end to early May	Mid-October to mid-November		
Peninsular India	May-June	End-October to mid-November		
Indo-gangetic plains	End-June to mid-July	End-October to mid-November	Late January to end-February	

#### Seed rate and plant geometry

Optimum plant density is essential for achieving high productivity and resource-use efficiency. The seed rate depends on purpose, seed size, plant type, season, sowing method, planter etc. Sowing should be done 5 cm deep on flat surface with a maize planter or seed-cum-fertilizer drill, provided with a planting attachment. The growing area for each plant can vary from 2,250 cm<sup>2</sup> (44,444 plants/ha) for sweet maize to 900 cm<sup>2</sup> (111,111 plants/ha) for baby maize. The early growth rate of winter maize is slow due to prevailing low



temperature and the plant density can be increased by 30-40% compared with the rainy-season crop (Dayanand and Jain, 1994). Following seed rate and planting geometry is recommended for different purposes of maize cultivation during rainy season (Table 3.7).

**Table 3.7** Seed rate and plant geometry of maize for different purposes

Purpose	Seed rate (kg/ha)	Plant geometry (row x plant, cm)	Plant population (no./ha)
Grain	20	60 x 20	83,333
		75 x 20	66,666
Sweet maize	8	75 x 25	53,333
		75 x 30	44,444
Baby maize	25	60 x 20	83,333
		60 x 15	111,111
Pop maize	12	60 x 20	83,333
Green cob (normal maize)	20	75 x 20	66,666
		60 x 20	83,333
Fodder	50	30 x 10	333,333

#### Seed treatment

To protect the crop from seed and major soil-borne diseases and insect-pests, it is essential to treat the seed with fungicides and insecticides before sowing as per the details given in Table 3.8.

**Table 3.8** Seed treatment against insect-pests and diseases

Disease/insect-pest	Fungicide/pesticide	Rate of application (g/kg seed)
<i>Turicum</i> leaf blight, banded leaf and sheath blight, <i>Maydis</i> leaf blight	Bavistin + captan in 1:1 ratio	2.0
Brown stripe downy mildew	Apron 35 sp	4.0
<i>Pythium</i> stalk rot	Captan	2.5
Termite and shoot fly	Imidacloprid	4.0

#### Methods of establishment/sowing

**Conventional:** Sowing is done with a maize planter on flat soil surface, and ridging is done subsequently either manually or with tractor- and bullock-drawn implements 15-20 days after sowing.

**Raised-bed (ridge):** In general, raised-bed sowing is the best establishment method for maize during rainy and winter seasons, both under excess moisture as well as limited irrigation availability conditions. Sowing should be done on the southern side of the east-west ridges/beds, 6-7 cm above the base of the ridge, for good germination. Sowing should be done at proper row spacing. The raised-bed planter having inclined plate, cupping or roller type seed-metering system should be used for sowing. This helps in proper placement of seed and



fertilizers in one operation, leading to good crop stand, higher productivity and resource-use efficiency. Using raised-bed technology, 20-30% irrigation water can be saved with higher productivity. Moreover, under temporary excess soil moisture/waterlogging due to heavy rains, the furrows act as drainage channels and crop can be saved from excess water stress. The crop grown with this method resists lodging and gives higher grain yield and water productivity than flat sowing, as ridge sowing provides better soil conditions for root development and nutrient uptake (Hassan *et al.*, 2005; Bakht *et al.*, 2011). Raised-beds (60 cm wide with 30 cm wide furrow) with irrigation applied in furrows result in significantly higher system productivity of maize compared to flat-bed (Kumar, 2008). For realizing the full potential of raised-bed technology, permanent beds are advisable wherein sowing can be done in a single pass without any preparatory tillage. Permanent beds are also beneficial under excess soil-moisture situations as the infiltration rate is much higher and crop can be saved from the temporary waterlogging injury. However, sowing on permanent raised-beds requires greater skill and efficient weed management.

*Zero-till sowing:* Maize can be successfully grown without any preparatory tillage under no-till situation after conventional or zero-till sown wheat. This results in lowering of cost of cultivation, higher profitability and better resource-use efficiency. This also helps in timely sowing of maize over large areas. Under such conditions, one should ensure adequate soil moisture at sowing, and seed and fertilizers should be placed in bands using zero-till seed-cum-fertilizer drill. The technology is suitable particularly for rice-winter maize and maize-wheat cropping systems in peninsular and eastern India. However, use of appropriate planter having suitable furrow opener and seed-metering system is the key for success of zero-till technology. If the field is infested with weeds, spraying of paraquat or glyphosate should be done before sowing. Further, integrated weed management involving use of suitable herbicides before and after sowing, and surface cover management with crop residues or mulching is essential.

*Reduced-till sowing:* In light to medium-textured soils, if the stubbles of the previous crop have been removed and there are no weeds, the preparatory tillage can be dispensed with and the crop can be sown directly after a pre-sowing irrigation. It is also advisable to use a roto-till seed-cum-fertilizer drill for simultaneous incorporation of left-over stubbles through shallow ploughing, and placement of seed and fertilizer in a single tractor operation so as to reduce the cost of cultivation.

*Furrow sowing:* During spring and summer seasons, evaporative losses of water from the soil under flat as well as raised-bed sowing are higher, and the crop suffers due to moisture stress, requiring frequent irrigations. Under such a situation, it is advisable to grow maize in furrows for better establishment, growth and productivity. Under this method, maize seeds may be planted in 10-15 cm furrows and covered with 3-4 cm soil. Once the seedlings have emerged, the furrows are filled with another 5 cm soil taking care that plants are not buried under soil. Later more soil is added along the crop row. The added soil supports the plants and helps them stay upright, even in high winds. As the roots



are deeper than maize planted on flat ground, furrow-planted maize often needs less watering. This method also helps to control weeds.

**Transplanting:** Under intensive cropping systems where fields are not vacated in time (by November), there are chances of delayed sowing of winter maize. Under such a situation, stand establishment is a problem due to low temperature. Therefore, transplanting is an alternative establishment technique for winter maize. For situations where fields are vacated late due to delayed harvesting of previous crop, such as rice, it is recommended to grow nursery and transplant the maize seedlings in furrows and apply irrigation water for proper establishment. Using this technique, temporal isolation can also be maintained in maize-growing regions for purity and good quality of seed production as well as quality protein maize grain. For 1 ha, about 700-800 m<sup>2</sup> area is required for nursery. The nursery should be raised during the second fortnight of November. The age of seedlings depends on growth, but in general, the seedlings should attain a height of about 15 cm for transplanting during December-January.

The use of transplanted seedlings shortens the growth period in the field, and consequently, even late-maturing, high-yielding cultivars can be cultivated during the growing season. Depending on temperature and other weather conditions, the transplanted maize develops rapidly and reaches flowering 10-20 days earlier than direct-seeded crop. Furthermore, the reduced crop cycle in the field results in savings in water used for irrigation. Where farmers use energy to pump and pay for water, such savings would increase the profit realized by farmers.

In a study at Ludhiana (Punjab), similar yields of maize grown after wheat have been obtained on loamy sand soil, regardless of tillage, method of establishment and straw mulching (Table 3.9). Permanent raised-beds and zero tillage systems offer many advantages including reduced inputs, such as energy (for powering tractors and pumps), labour and machinery for tillage, and irrigation water savings. The permanent beds perform even better on fine-textured soils prone to waterlogging, which, in general, yield poorly on

**Table 3.9** Grain yield, water-use efficiency and economics of maize under different tillage and methods of establishment at Ludhiana (mean of 5 years)

Treatment	Grain yield (tonnes/ha)	Water-use efficiency (kg/ha-cm)	Net returns ( $\times 10^3$ ₹/ha)
Conventional tillage (flat)	5.54	80.8	33.05
Zero tillage (flat)	5.57	79.8	34.64
Zero tillage (flat) + wheat straw mulch	5.68	82.6	35.06
Fresh raised-beds	5.57	86.8	32.96
Permanent raised-beds	5.62	85.8	34.52
Permanent raised-bed + wheat straw mulch	5.75	88.8	35.34
CD (P = 0.05)	NS	3.0	1.85

Source: Ram *et al.* (2011)



conventional, flat layouts during the monsoons. When both net returns (ignoring the cost of mulch) and water-use efficiency factors are taken into account, permanent raised-bed + straw mulching may be more profitable for sustainable maize-wheat cropping system in north-western India.

### NUTRIENT MANAGEMENT

Maize is an exhaustive crop and requires a balanced supply all the 3 major nutrients (N, P and k) as well as zinc on most soils of the Indo-Gangetic plain. The hybrids of maize are very responsive to external supply of nutrients. Besides chemical fertilizers, the crop is very responsive to organic manures. Application rate of nutrients depends on soil-nutrient status and cropping system followed. Nitrogen is needed in large amounts and adequate supply of N throughout the growing season is necessary for realizing potential yields. The response of maize is obtained up to 120 kg N/ha in rainy season, and 180 kg N/ha in winter in Punjab (Narang *et al.*, 1989). Further, application of 40-60 kg P<sub>2</sub>O<sub>5</sub> and 20-30 kg K<sub>2</sub>O along with 25 kg ZnSO<sub>4</sub>/ha is also recommended, depending on native soil fertility and growing season. Similarly, nutrient requirement of baby corn is higher than grain crop as it is planted at relatively high density. Optimum N rates ranging from 150 to 180 kg/ha along with 60-70 kg P<sub>2</sub>O<sub>5</sub> and 40-50 kg K<sub>2</sub>O/ha have been reported in different parts of the country (Thakur, 2000; Saha and Mondol, 2006; Singh *et al.*, 2011). General recommended doses of chemical fertilizers for medium-fertility soils are given in Table 3.10.

**Table 3.10** General recommended doses of fertilizer nutrients for maize grain crop on medium fertility soils (kg/ha)

Crop/variety/situation	N	P <sub>2</sub> O <sub>5</sub> *	K <sub>2</sub> O**
Rainy season			
Irrigated, full-season variety/hybrid	120	60	30
Rainfed, short-duration variety/hybrid	80	40	20
Winter season	175	60	30
Spring season	120	60	30

\*In P- and S-deficient soils, apply single superphosphate or sulphated P fertilizer (13 : 33 : 0 : 15)

\*\*Apply K only if the soil test shows deficiency of K

Full dose of P and K along with one-third of N should be applied at the time of sowing. Basal drilling of fertilizers should be done in bands along side the seed at desired soil depth using seed-cum-fertilizer drill. Top-dressing of remaining N at knee-high and pre-tasseling stages in equal splits should be done by placing or dropping the fertilizer closer to the plant base.

For getting higher yields, the nutrient applications should be scheduled in such a way so as to match the nutrient-supplying capacity of the soil and the plant demand (site-specific nutrient management approach) keeping in view the preceding crop grown in the cropping system. Integrated nutrient management is an important strategy in maize production systems. For higher economic



returns from maize, green manuring or application of 10-20 tonnes farmyard manure (FYM)/ha, 10-15 days prior to sowing is recommended. Further, chemical fertilizers should be applied based on soil-test based recommendations.

### Green manuring

Green manuring with cowpea, sunnhemp (*Crotalaria* sp.) or *Sesbania* is recommended for higher productivity of maize. The application of organic matter to the soil ensures good tilth and improves its water-holding capacity. Application of N fertilizer more than the recommended dose is no substitute for FYM or green manuring. The green-manure crop should be sown during the second fortnight of April using 30 kg/ha seed of cowpea or 50 kg seed/ha of sunnhemp and *Sesbania*. Green manure should be buried when about 50 days old and allowed to decompose for 10 days before sowing of maize. In case dual-purpose summer mungbean or cowpea is grown, the stover should be buried before sowing. The stover of cowpea and greengram adds about 50 kg N/ha into soil compared to 130 kg N/ha through *Sesbania* (Sharma and Behera, 2009a). In a study on maize-wheat cropping system, the response of maize to N fertilizer rates was quadratic, and there was saving of N to the extent of 57-67 kg/ha with *Sesbania*, and 37-49 kg/ha with cowpea and greengram (Fig. 3.4).

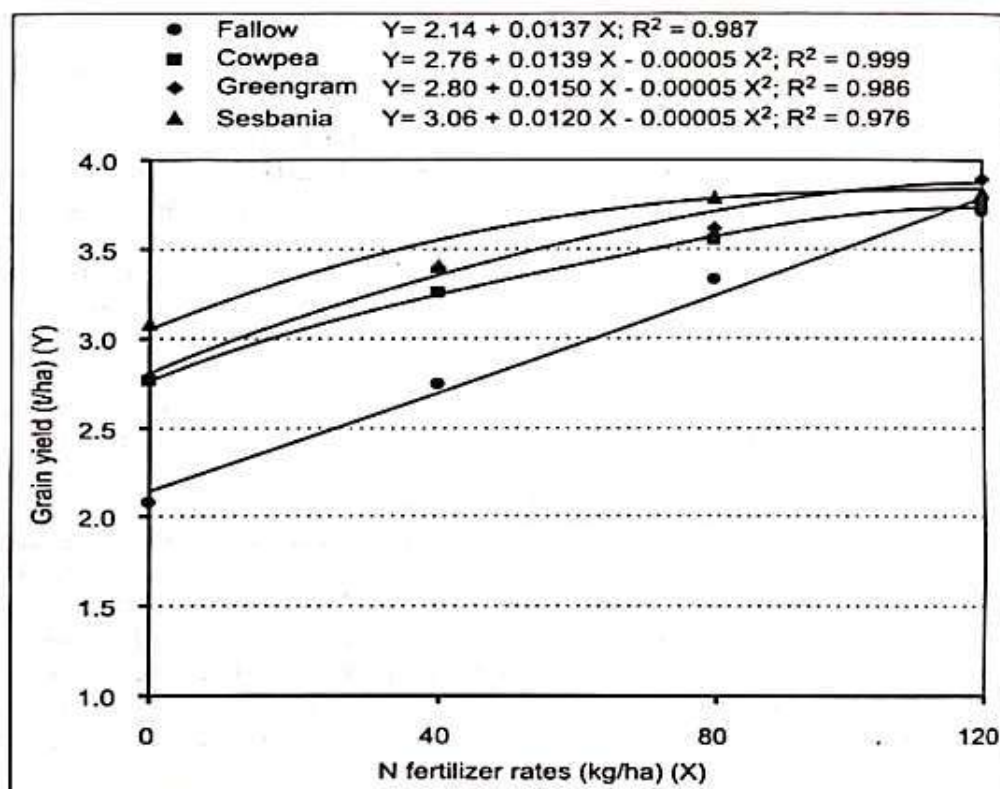


Fig. 3.4. Response of maize to N application under different summer legumes (Source: Sharma and Behera, 2009a)

### Zinc deficiency

Zinc deficiency is widespread in many areas where high-yielding varieties of maize are grown. Zinc deficiency in maize is known as 'white bud'. The deficiency symptoms appear within two weeks of seedling emergence. A broad band of white or very light yellow tissue with reddish veins appear, on each side of the mid-rib, beginning at the base of the second or third leaf from the top of the plant. The white patch later extends in stripes towards the tip parallel to the mid-rib. The mid-rib and leaf margins remain green. The plants remain stunted and have short internodes. In the case of mild deficiency, there is a white stripe in the upper leaves. The mild deficiency disappears by the mid-season but the silking and tasseling are delayed. When zinc deficiency is noticed in the preceding crop, broadcast 25 kg  $ZnSO_4 \cdot 7H_2O$  or 15 kg  $ZnSO_4 \cdot H_2O$  at sowing mixed with an equal quantity of dry soil and incorporate into the soil. When  $ZnSO_4$  is to be applied after the deficiency symptoms appear on the crop, apply 25 kg  $ZnSO_4 \cdot 7H_2O$  or 15 kg  $ZnSO_4 \cdot H_2O$  mixed with an equal quantity of dry soil along rows, hoe it into the soil and then irrigate the field. When the symptoms are observed late in the season and interculture is not possible, spray zinc sulphate and lime mixture prepared by mixing 3.0 kg  $ZnSO_4 \cdot 7H_2O$  + 1.5 kg unslaked lime or 2.0 kg  $ZnSO_4 \cdot H_2O$  + 1.0 kg unslaked lime with 500 litres water/ha.

### WATER MANAGEMENT

About 80% of maize is cultivated during the monsoon season, mostly under rainfed conditions, while the crop during winter and spring seasons is almost fully irrigated. The overall irrigated area under maize is only 25% compared with 91% under wheat and 59% under rice (FAI, 2010-11). In areas where assured irrigation facilities are available, water must be supplied at critical growth stages. Young seedling, knee-high, flowering, and grain-filling are the most sensitive stages for moisture stress; and hence, irrigation should be ensured at these stages. Generally, 3-5 irrigations may be required in monsoon-season crop, depending on the rainfall and irrigation water supply. For different water-availability scenarios, the irrigation scheduling can be as follows: (i) 5 irrigations at 6-leaf, late knee-high, tasseling, 50% silking and dough stages; (ii) 4 irrigations at 6-leaf, late knee-high, 50% silking and dough stages; and (iii) 3 irrigations at early knee-high, tasseling and 50% silking stages. In the raised-bed crop, the first irrigation should be applied carefully so that water does not overflow on the ridges/beds. In general, the irrigation should be applied in furrows up to two-thirds height of the ridges/beds. Under limited water-availability conditions, the irrigation can be applied in alternate furrows without much adverse effect on crop productivity. In rainfed areas, tied-ridges are helpful in conserving the rainwater for its availability in the root zone for a longer period. Tied ridging is a type of surface configuration whereby the ridges are 'tied' to each other at regular intervals by cross-dams, blocking the furrow and can be used for conserving rainfall and preventing runoff.

For winter maize, it is advisable to keep soil wet with frequent and mild irrigations during the period from mid-December to mid-February to protect the



crop from low temperature and frost injury. First irrigation should be applied at 3-4 weeks after germination, and subsequent irrigations at 4-5 week intervals up to mid-March, and thereafter at 1-2 weeks intervals depending on rainfall and temperature. It is desirable to apply light irrigations as the flooded crop can suffer from cold damage. In the event of frost expectation, additional protective irrigation should be given. The crop grown during winter and spring seasons should not be subjected to moisture stress at flowering and grain-development stages, otherwise there may be desiccation of pollen, poor fertilization and grain filling during the hot summer months.

Maize can tolerate heavy rains provided fields are not subjected to excessive soil wetness or flooding for prolonged periods. Flooding particularly at young stage causes damage to the crop (Narang *et al.*, 1994). To avoid flooding, drain out the excess water by making a drain of adequate capacity at the lower end of the field. If such a damage does occur, 2-3 sprays of 3% urea solution at weekly interval may be made. Additional application of 30-40 kg N/ha is also recommended after the flooding is over to mitigate the flood damage.

### WEED MANAGEMENT

Weeds are a serious problem in maize due to wide row spacings, and warm and humid weather during rainy season, and slow initial growth in the winter season. The major weed species in *kharif* season crop include: *Echinochloa colonum* (barnyard grass), *Eleusine indica* (goose grass), *Setaria glauca* (yellow foxtail), *Eragrostis tenella* (love grass), *Digitaria sanguinalis* (crab grass), *Sorghum halepense* (Johnson grass) and *Cynodon dactylon* (bermuda grass) among grassy species; *Trianthema portulacastrum* (horse purselane), *Digera arvensis* (*tandla*), *Amaranthus viridis* (pig weed), *Euphorbia hirta* (spurge), *Phyllanthus niruri* (*niruri*), *Celosia argentea* (white cockscomb), *Ageratum conyzoides* (bill goat weed) and *Commelina benghalensis* (tropical spiderwort) among broad-leaved species; and *Cyperus rotundus* (purple nutsedge) and *Cyperus esculentus* (yellow nutsedge) among sedges. On the other hand, the predominant weed species in *rabi* season crop are: *Phalaris minor* (little seed canary grass), *Avena ludoviciana* (wild oat) and *Poa annua* (annual blue grass) among grassy species and *Chenopodium album* (common lambsquarter), *Melilotus indica* (wild senji), *Coronopus didymus* (swine grass), *Convolvulus arvensis* (field bind weed) and *Anagallis arvensis* (pimpernel) among broad-leaved species. These weeds compete with crop for nutrients, water and other resources, and cause yield losses up to 35%. Therefore, timely weed management is needed for achieving higher yield. Weeds must be controlled during the initial 4-6 weeks period, after which, the canopy develops thick enough to smother the weeds. Conventionally, the weeds are controlled mechanically by hoeing and animal-drawn implements. Ploughing in standing crop at 20-25 days of growth, called as 'haloding' in the western Himalayan region, helps in uprooting of weeds and earthing-up of plants. This also helps in the formation of furrows, which retain the rainwater and sustain the crop during drought period.



The use of herbicides for weed control in maize is quite effective and widespread. Atrazine and simazine are the two most popular herbicides for maize that check the emergence and growth of a wide spectrum of weeds. Pre-emergence application of atrazine or simazine @ 1.0-1.5 kg/ha in 600 litres water gives effective control of weeds. The dose can be reduced by 40% in light-textured soils. Atrazine can also be sprayed as 20 cm wide band over the crop rows up to 10 days after sowing followed by hoeing at 15-30 days of growth or as blanket spray up to 10 days after sowing (Sharma *et al.*, 2000). In areas where *Trianthema portulacastrum* is not a problem, alachlor @ 2.0 kg/ha as pre-emergence or trifluralin @ 1.0 kg/ha as pre-plant incorporation can be used (PAU, 2010-11). During spraying, the person who is doing the spray should move backward so that the atrazine film on the soil surface is not disturbed. Preferably 3-boom flat-fan nozzle should be used for proper ground coverage and saving time. Spraying of the herbicide should be done at recommended rates to minimize residual toxicity to crops sown after maize. The spray solution left-over in the bucket or spray tank should not be thrown into the field because it will pose serious adverse effect on the following winter-season crop.

For the control of hardy weeds like *Brachiaria reptans*, *Arachne racemosa* (acrachne) and *Commelina benghalensis* (tropical spidewort, wandering jaw), pre-emergence tank-mix application of atrazine (1.0 kg/ha) + pendimethalin (0.75 kg/ha) has been found to be more effective than atrazine alone. Further, one to two hoeings are also recommended for soil aeration and removal of the weeds that emerge after about a month of sowing. Under heavy weed infestation, post-emergence application of paraquat can be done as a protected spray using hood in the inter-row zone, which gives almost a similar effect as hand hoeing (Singh *et al.*, 2007). In areas where zero-tillage is practised, pre-plant application (10-15 days prior to seeding) of non-selective herbicides, viz. glyphosate @ 1.0 kg/ha or paraquat @ 0.5 kg/ha in 600 litres water is recommended to kill the existing weed growth.

Cultural control of weeds by non-chemical means can be achieved by adopting intercropping with legumes, and live or brought-in mulching. Fast-growing legumes, such as *Sesbania*, sunnhemp and cowpea can be intercropped with maize and harvested at 30 days of growth to be spread as live mulch in the inter-row spaces (Sharma *et al.*, 2010). Alternatively, brought-in mulching with various vegetative materials like twigs of *Lantana*, *Leucaena* or kudzu (*Peuraria hirsuta*) can be applied during the maize-growing season (Sharma *et al.*, 2011). These practices help not only in weed control but also in conserving moisture and nutrients, leading to higher productivity under rainfed conditions.

Weed management in many crops including maize has changed greatly with the launch of herbicide-resistant crops since mid-1990s, especially in North and South America. Presently, about 160 million/ha is planted to transgenic crops, of which 60% is planted to herbicide-resistant crops, including soybean, maize, cotton, canola, sugarbeet and alfalfa, and 22% to stacked herbicide and insect traits (Reddy and Nandula, 2012). Glufosinate-resistant maize was commercialized for the first time in 1997, and was combined with glyphosate-resistant



maize as a 'double stacked trait' in the mid-2000s. Simple and flexible weed-control techniques have been designed for broad-spectrum control of weeds with glyphosate in glyphosate-resistant crop. In India, however, herbicide-resistant maize has not yet been introduced for commercial cultivation.

### INSECT-PEST MANAGEMENT

#### Maize borer

Maize borer (*Chilo partellus*) is the borer insect of maize during the monsoon season, and it is considered as a serious pest throughout the country. *Chilo* lays eggs 10-25 days after germination on lower side of the leaves. The larvae enter in the whorl and cause damage to the leaves. In a young plant, the growing point is killed and a dead-heart results. *Sesamia inferens*, another borer, attacks maize during the winter season, particularly in peninsular India. The moth of *Sesamia* is nocturnal and lays eggs on lower leaf sheath. The larvae of *Sesamia* enter the plant near the base and cause damage to stem.

For control of *Chilo* and *Sesamia*, integrated control measures should be followed: (i) borer larvae hibernating in plant remnants like stubbles, stalks, cobs and cores should be killed, (ii) plough up the fields after harvesting the maize crop, collect the stubbles and burn them, (iii) for seed, keep only healthy cobs, free from borer attack, (iv) remove and destroy the plants showing severe borer injury while hoeing the crop, (v) spray the crop 2-3 weeks after sowing or as soon as borer injury to the leaves is noticed with synthetic pyrethroids, such as fenvalerate, cypermethrin and deltamethrin or with insecticides such as endosulfan, monocrotophos and carbaryl, (vi) *Chilo* can also be controlled by release of Trichocards (*Trichogramma chilonis*) having 100,000 eggs of *Corcyra cephalonica* parasitized by *Trichogramma chilonis* on 10-15 days old maize crop, and (vii) intercropping of cowpea with maize is an eco-friendly option for reducing the incidence of *Chilo*.

#### Shoot fly

It is a serious pest of spring-sown crop. It attacks very young (3-4 days old) seedlings, producing deformed, twisted and dead-hearted plants. For control, apply carbofuran or thimet granules in the furrows at the time of sowing.

#### Army worm

The larvae feed on tender leaves of the whorl or eat out the whole leaf including the mid-rib. Presence of faecal pellets on the whorl indicates the occurrence of this pest. Attack is relatively more on the border rows adjoining wheat field in March. The insecticides recommended against maize-borer are also effective in controlling army worms.

#### Hairy caterpillar

These appear in an epidemic form and cause serious damage by feeding on the leaves and tender stems. When young, they feed gregariously. The grown-

up caterpillars migrate from one field to another. For control, adopt the following measures: (i) use light traps for the destruction of adults, (ii) destroy the infested leaves or plant by burying them underground, (iii) the grown-up caterpillars can be destroyed by crushing under feet or picking and putting them into kerosinized water, and (iv) spray insecticides, such as quinalphos or dichlorvos.

#### **Termite**

These are also a major problem in many areas. Fipronil granules should be applied @ 20 kg/ha followed by light irrigation. If termite incidence is in patches, fipronil should be applied as spot application.

#### **Mite**

These attack the young crop or when it is nearing maturity. The affected leaves turn pale and can be recognized from the presence of dusty webs. Monocrotophos is recommended for their control.

### **DISEASE MANAGEMENT**

There are several diseases of maize that occur during different seasons in various parts of the country. On an average, these diseases cause an yield loss of about 10-15%. Important diseases of maize and their management practices are described here.

#### ***Turcicum* leaf blight**

This disease is distributed throughout the country, and the symptoms appear on leaves as long, elliptical, greyish-green or tan lesions, ranging from 2.5 to 15.0 cm in length. For control, spray zineb or maneb @ 2.5-4.0 g/litre water (2-4 applications) at 8-10 days interval. The crop debris should be ploughed down.

#### ***Maydis* leaf blight**

This disease also occurs in almost all maize-growing areas, and the symptoms appear as lesions on the leaves elongated between the veins, 2-6 mm × 3-22 mm with limited margins having buff to brown borders. Sometimes, the symptoms also appear on the leaf sheath, cob husk and ears. For effective control, spray dithane Z-78 or zineb @ 2.4-4.0 g/litre water (2-4 applications) at 8-10 days interval after the first appearance of symptoms. In addition, the crop debris should be ploughed down, and resistant/tolerant cultivars should be grown.

#### ***Polysora* rust**

This disease appears mainly in peninsular India. The symptoms show appearance of circular to elongate light cinnamon brown and circular to oval 0.2-2.0 mm long densely scattered lesions on the upper leaf. The uredospores are yellowish to golden. For effective control of polysora rust, three sprays of dithane M-45 @ 2.0-2.5 g/litre beginning from first appearance of symptoms at 15 days interval are required.



**Banded leaf and sheath blight**

This disease mainly occurs in north-western hilly and plain areas, central and eastern parts of the country. Appearance of white lesions on leaves and sheath, and purplish or brown horizontal bands present on white lesions are the characteristic symptoms of this disease. Seed treatment with peat-based formulation of *Pseudomonas fluorescence* @ 16 g/kg seed or as soil application @ 7 g/litre water (soil drenching) or foliar spray of sheethmar (validamycin) @ 2.7 ml/litre water provides effective control. Stripping of 2 lower leaves along with leaf sheath is also recommended.

**Post-flowering stalk rots**

Post-flowering stalk rots caused by *Macrophomia phaseolina*, *Cephalosporium maydis* and *Fusarium* species, occur mainly in Rajasthan, Uttar Pradesh, Bihar and Andhra Pradesh, when the crop enters senescence phase. All stalk rots result in wilting of plants after flowering, followed by weakening of the stem. The pathogen commonly affects the root-crown regions and lower internodes. Opening of split of stalk shows pink-purple discolouration. Infection with *M. phaseolina* results in black sporulation in the pith region. For effective control, water stress at flowering should be avoided. A mixture prepared with inoculation of biocontrol agent, *Trichoderma* mixed with FYM and covering with wet gunny bags for 10 days should be applied in the furrows before sowing. It is advisable to practice crop rotation with recommended varieties to minimize the incidence.

**Downy mildew**

Many areas of north-western, central and eastern India are prone to downy mildew (*Peronosclerospora philippinensis*). These cause lesions on lower leaves as narrow chlorosis strips. Strips extend in parallel fashion with well-defined margins delineated by veins. Downy whitish to creamy growth usually appears on the ventral surface of the infected leaves corresponding to strips. The infected plants are stunted and are highly susceptible to Maydis leaf blight. Most of the infected plants die pre-maturely. For control, the infected plants should be rogued out and destroyed. Early sowing before onset of rains minimizes the incidence. Seed treatment with fungicides like apron 35 ws @ 2.5 g/kg seed is recommended. Young seedlings can be protected from infection by two sprays of indofil M-45 at 10 days interval.

**SPECIALITY MAIZE TYPES**

Other than grain, maize is also cultivated for various other purposes. The various speciality maize types are: quality protein maize (QPM), baby maize, sweet maize, pop maize, waxy maize, high oil maize etc. In India, QPM, baby and sweet maize types are becoming popular among farmers (Brar and Kumar, 2012). Different types of speciality maize varieties/hybrids are recommended for cultivation (Table 3.11).



**Table 3.11** Varieties/hybrids of specialty maize recommended for cultivation

Specialty maize types	Varieties/ hybrids
Quality protein maize	HQPM 1 and HQPM 5 (all states of India), HQPM 7, Vivek and QPM 9 (Peninsular India), Shaktiman 1, Shaktiman 2, Shaktiman 3 and Shaktiman 4 (Bihar); Shakti 1
Baby maize	HM 4, Partap 1, VL Baby Corn 1, Prakash, Kesri
Sweet maize	Madhuri, Win Orange, Priya, Punjab Sweet Maize 1
Pop maize	Jawahar, Amber, Pearl and VL Pop corn
Fodder	African Tall, J 1006, Partap Chari 6

### Quality protein maize

Discovery of Opaque 2 (O 2) mutant opened possibilities for improvement of protein quality of maize, which later led to the development of quality protein maize. The QPM is nutritionally superior to normal maize, and thus, it is important not only for food and nutritional security, but also for quality feed for poultry and animal sectors. The QPM is characterized by the presence of balanced amount of amino acids with high content of lysine and tryptophan, and low content of leucine and isoleucine. The biological value of protein in QPM (80%) is double of that in normal maize (<50%), and close to the milk protein (90%). The production technology of QPM is the same as of normal grain maize, except maintenance of isolation distance to ensure its purity.

### Baby maize

Baby maize is a young finger-like unfertilized cob with 1-3 cm emerged silk preferably harvested within 1-3 days of silk emergence, depending on the growing season. The desirable size of baby maize is 6-11 cm length and 1.0-1.5 cm diameter with regular row ovule arrangement. The most preferred colour by the consumers and exporters is generally creamish to very light yellow. The nutritional quality of baby maize is at par or even superior to some of the seasonal vegetables. It can be eaten raw as salad and in preparation of different recipes, such as chutney, soup, *pakora*, mix vegetables, pickles, candy, *murabba*, *kheer*, *halwa*, *raita*, etc. Besides proteins, vitamins and iron, it is one of the richest source of phosphorus. It is a good source of fibre and easy to digest. It is almost free from residual effects of pesticides. It has great potential both for internal consumption as well as export. Baby maize salad and soup is a delicacy in hotels, airlines and shipping companies because of crispiness and sweet flavour.

The sowing of baby maize can be done at any time from April to August. It is possible to have two or more crops from the same piece of land as this crop matures in < 60 days. Staggered sowing should be done to maintain the supply to market as per requirement. In general, the cultivation practices of baby maize are similar to the grain crop, except: (i) higher plant population (60 cm × 15 cm), (ii) higher dose of N, (iii) preference for early-maturing single-cross hybrids, and (iv) harvesting within 1-3 days of silk emergence as the ears picked later would be pithy, woody and of poor quality. It is also important to remove



the tassel as soon as it appears to check the pollination. Ears with single layer of husk should be taken to the market after dehusking.

### **Sweet maize**

Sweet maize is one of the most popular vegetables in the USA and Europe. It is a very delicious and rich source of energy, vitamin C and A. It is eaten as raw, boiled or steamed green cob/grains. It is also used in preparation of soup, salad and other recipes. Sweet maize is becoming very popular in urban areas of our country. Generally sweet maize is early in maturity, and harvested in 70-75 days during the rainy season. Green cobs are harvested 18-20 days after pollination; however, the duration may vary with the season. At harvest, the moisture content is about 70% in the grain, and sugar content varies from 11 to 20%. Sweet maize is generally dull yellow and white, and the former is generally preferred. Sowing of sweet maize should not be done when temperature is  $<16^{\circ}\text{C}$ . The picking should be done in the morning or evening. Since exposure to high temperature after picking leads to loss in flavour, green cobs should be immediately transported to the cold storage.

### **Pop maize**

It is hard endosperm flint maize and used as one of the common snack items in many parts of the country. It is liked because of its light, porous and crunchy texture. The pop maize flour can be used for preparing many traditional dishes. Kernels of pop maize are relatively small and oval or round. When heated at about  $170^{\circ}\text{C}$ , the grains swell and burst, turning inside out.

### **Waxy maize**

Waxy maize originated in China, and it is now largely used in the USA for food and industrial purposes. Grains of waxy maize give wax-like appearance. It has 100% amylopectin starch compared with 70% in normal maize types.

### **High oil maize**

Most of the normal maize varieties and hybrids have 3-4% oil content but some lines with  $> 6\%$  oil are also available. In maize grain, about 95% of the total oil is in the germ. In general, oil and starch content have inverse relationship. The maize oil has low content of saturated fatty acid and is considered to be one of the best quality cooking oil. In the USA, high oil maize types are cultivated on contractual basis and remunerative price is paid to the farmers. In India its cultivation is not economical because it is not sold on premium basis. However,  $>60,000$  tonnes of maize oil is made available for various purposes.

### **Fodder maize**

Maize can be used as fodder at any stage of growth, although quality deteriorates after anthesis. To maintain better quality of fodder in terms of digestibility and palatability, detasseling is advocated. The tall, leafy and long-duration cultivars, preferably composites or advance generation hybrids are recommended for fodder cultivation.



### HARVESTING AND THRESHING

Maize can be harvested at physiological maturity, i.e. when the stalks and leaves are somewhat green but the husk cover has dried and turned brown. In the fields where the next-winter-season crop is to be sown, stalks along with cobs are harvested and stacked. Maize dehusker-cum-sheller can be used for shelling of unhusked cobs. For better results, maize (with husk) should be shelled when the moisture content ranges between 15 and 20%. Maize shellers operated manually or with power are available in the market. Conventional grain-combines can also be used for threshing maize with husk to save labour involved in dehusking. However, some adjustments are necessary. The maize ears should preferably be dried for 3-4 days after harvesting. Commercial grain yields of maize are usually expressed on a 15.5% grain-moisture basis.

### CROPPING SYSTEMS

Maize has wide adaptability and compatibility under diverse soil and climatic conditions. Therefore, it is cultivated in sequence or in association with different crops under varied agro-ecologies of the country. Maize has compatibility with several crops of different growth habit that led to development of various intercropping systems. In such systems, the nutrients should be applied as per requirement of both the crops for higher productivity. Precautions should be taken in application of herbicides ensuring selectivity for both the crops in the system. Maize is an ideal crop for intercropping, and therefore, it is considered as one of the potential drivers of crop diversification under different situations. It is often intercropped with soybean, groundnut, greengram, cowpea, blackgram, pigeonpea, sesame, pigeonpea, sugarcane, rice etc. Intercropping of maize with legumes, such as cowpea, greengram and groundnut not only improved the productivity and profitability, but the incorporation of legume residues also resulted in saving of about 21 kg N/ha in the following wheat crop (Sharma and Behera, 2009b). In peri-urban interface, maize-based high-value intercropping systems involving vegetables and flowers are gaining importance owing to market-driven farming.

Among different maize-based sequence cropping systems, maize-wheat ranks first with about 1.8 million ha area, mainly concentrated in rainfed ecologies. The other double cropping systems involving maize are: maize-mustard, maize-chickpea, cotton-winter maize etc. Triple cropping systems involving maize in north-western plains zone are: cowpea/*bajra*/maize (fodder)-maize-wheat, green manuring-maize-wheat, maize-potato-wheat, maize-potato-greengram, maize-potato/*toria*-sunflower, maize-potato-onion, maize-potato-mentha, maize (August)-wheat/*celery*-*bajra* fodder, and maize-*gobhi sarson*-summer greengram (PAU, 2010-11). At New Delhi, quadruple cropping systems developed in the 1970s are: maize-*toria*/potato-wheat-summer greengram, and maize (green cobs)-radish/turnip-wheat-greengram (Sharma, 2007).

In recent times, rice-winter maize has emerged as a potential cropping system on 3.5 million ha in Asia (Timsina *et al.*, 2011). This cropping system is rapidly spreading in southern and north-eastern India owing to the rising



demand for maize by the poultry and fish sectors, and presently covers an area of 0.5 million ha. Studies carried out under various soil and climatic conditions revealed that maize-based cropping systems are better user of available resources compared to rice-wheat and rice-rice systems (Dass *et al.*, 2011). Major maize-based cropping systems in irrigated and rainfed conditions of India are given in Table 3.12.

**Table 3.12** Maize-based cropping systems in different agro-climatic zones of India

Agro-climatic region	Cropping system	
	Irrigated	Rainfed
Western Himalayan region	Maize-wheat	Maize-mustard
	Maize-potato-wheat	Maize-legumes
	Maize-wheat-greengram	
	Maize-mustard	
	Maize-sugarcane	
Eastern Himalayan region	Summer rice-maize-mustard	Sesame-rice+maize
	Maize-maize	
	Maize-maize-legumes	
Lower Gangetic Plain region	Autumn rice-maize	Rice-maize
	Jute-rice-maize	
Middle Gangetic Plain region	Maize-early potato-wheat-greengram	Maize-wheat
	Maize-wheat	
	Maize-wheat-greengram	
	Maize-wheat-urdbean	
	Maize-sugarcane-mungbean	
Upper Gangetic Plain region	Maize-wheat	Maize-wheat
	Maize-wheat-greengram	Maize-barley
	Maize-potato-wheat	Maize-safflower
	Maize-potato-sunflower	
	Maize-potato-onion	
	Maize-potato-sugarcane-ratoon	
Trans Gangetic Plain region	Rice-potato-maize	
	Maize-wheat	
	Maize-wheat-greengram	
	Maize-potato-wheat	
	Maize-potato-sunflower	
	Maize-potato-onion	
	Greengram-maize-toria-wheat	
Maize-potato-mungbean		
Eastern plateau and hills region	Maize-groundnut-vegetables	Rice-potato-maize
	Maize-wheat-vegetables	Jute-maize-cowpea
Central plateau and hills region	Maize-wheat	Maize-groundnut

Table 3.12 contd

**Table 3.12 concluded**

Agro-climatic region	Cropping system	
	Irrigated	Rainfed
Western plateau and hills region	Sugarcane + maize	
Southern plateau and hills region	Rice–maize Maize–rice	Sorghum–maize Maize–sorghum–pulses Maize–potato–groundnut
East coast plain and hills region	Rice–maize–pearlmillet Maize–rice Rice–maize Rice–rice–maize	Maize–maize–pearlmillet Rice–maize + cowpea
West coast plain and hills region	Maize–pulses Rice–maize	Rice–maize Groundnut–maize
Gujarat plains and hills region	Maize–wheat	Rice–maize
Western dry region	Maize–mustard Maize–chickpea	Maize + legumes
Island region	Rice–maize	Maize–rice Rice–maize + cowpea Rice–maize–urdbean Rice–rice–maize

Source: Dass *et al.* (2011)

### VALUE-ADDITION

Value-addition in maize has a great potential. There are several value-added products of maize, particularly QPM and baby maize that not only increase the farm income but also provide employment to rural youth and farm women. Value-added products developed using normal maize and QPM are: (i) traditional preparations—*ladoo*, *halva*, *kheer*, *chapati*, *sev*, *mathri*, *pakora*, and *cheela*; (ii) popped products—popcorn and popped *ladoo*; (iii) baked products: bread, *non-khatai* and cake; (iv) extruded products—vermicelli and pasta; and (v) convenience foods—instant *idli* mix, instant *dhokla* mix, porridge mix and sprouted *chat*. Similarly, a wide range of products from baby maize have been developed: (i) traditional products—*pakoda*, *cutlet*, *chat*, salad, dry vegetable, *kofta*, mixed vegetable, and *raita*; (ii) sweet products—*halwa*, *kheer*, and *burfi*; (iii) preserved products—jam, chutney, pickle, candy, and *murabba*; and (iv) Chinese products—soup Manchurian, baby corn chili, chowmin, sweet and sour vegetable.

### SUMMARY

Maize is the most widely distributed crop, being grown over a range of agro-climatic zones, from below sea-level to elevation reaching 4,000 m, from 60°N to 40°S latitude, arid to humid high rainfall zone, cold and warm temperature



regimes, and in sandy to clayey soils. Among cereal foodgrains, maize has the highest productivity, and average yields of 4-6 tonnes/ha are common in the monsoon crop, while yields of 6-8 tonnes/ha have been recorded in winter season in most parts of India. Yield improvement of maize in the past has occurred owing to increased dry-matter accumulation, which may be in part attributable to 'stay green' characteristic, but most of the yield improvement appears to be the result of increased stress tolerance. The adoption of low-input management practices in maize production will increase the need for more stress-tolerant genotypes, and stress tolerance will continue to be the most important trait in maize breeding for grain yield. The important aspects of maize like origin, plant characteristics and production technologies are summarized as follows:

- Maize originated from its closest relative, teosinte and the centres of origin are Peru, Bolivia and Ecuador.
- World-wide maize is cultivated on 159 million ha (> 150 countries) with a total production of 819 million tonnes and yield of 5.2 tonnes/ha.
- USA (40%) is the largest producer of maize grain followed by China (20.0%) and Brazil (6.3%).
- In India, maize (area 8.3 million ha, production 21 million tonnes) is the third most important cereal crop after rice and wheat.
- Karnataka (20.5%) has largest area under maize followed by Andhra Pradesh (19.6%), Maharashtra (10.7%) and Rajasthan (9.5%)
- High-yielding varieties and hybrids of maize occupy 60% of the total area, compared with 85% in wheat and 74% in rice.
- Maize is used as a staple human food, livestock and poultry feed, and for fermentation and many industrial purposes.
- In India, about 85% of the maize produced is consumed as human food and animal feed including poultry.
- It is also used for production of bio-fuel (ethanol).
- Maize is an annual plant belonging to the tribe Tripsaceae (Maydeae) of grass family (Gramineae or Poaceae).
- Maize is a tall plant with a fibrous root system.
- It has a single leaf at each node, and two successive leaves along the stem of maize have an approximately opposite azimuthal orientation
- Maize is monoecious, with staminate flowers on the terminal branched end of a tall erect stem (the tassel) and pistillate flowers on the axillary shoots (ear shoots).
- It is cross-pollinated crop. Seed of composites and synthetics can be used year after year without yield loss.
- Maize is grown round the year in all seasons, viz. monsoon, post-monsoon, winter and spring, in different parts of the country
- The most suitable temperature for germination is 21°C and for growth 32°C. Maize is susceptible to frost.
- Maize can be grown successfully on a wide range of soils, ranging from loamy sand to clay loam.
- Maize crop needs well aerated, moist soil. One deep ploughing and 2-4 harrowing with planking are sufficient for seedbed preparation.



- The growing area for each plant can vary from 2,250 cm<sup>2</sup> (44,444 plants/ha) for sweet maize to 900 cm<sup>2</sup> (111,111 plants/ha) for baby maize.
- Raised-bed sowing is the best establishment method for maize during the rainy and winter seasons, both under excess moisture as well as limited irrigation availability conditions and increase yield and saves 20-30% irrigation water
- Under intensive cropping situations, where fields are vacated late due to delayed harvesting of previous crop, it can be grown with transplanting method; for 1 ha, about 700-800 m<sup>2</sup> area is required for nursery.
- The response of maize is obtained up to 120 kg N/ha in the rainy season, and 180 kg N/ha in the winter season in Punjab.
- Application of 40-60 kg P<sub>2</sub>O<sub>5</sub> and 20-30 kg K<sub>2</sub>O along with 25 kg ZnSO<sub>4</sub>/ha is also recommended.
- Nutrient requirement of baby corn is 150-180 kg N, 60-70 kg P<sub>2</sub>O<sub>5</sub> and 40-50 kg K<sub>2</sub>O/ha
- Green manuring or application of 10-20 tonnes FYM/ha, 10-15 days prior to sowing, increases yield and income.
- Green manuring with cowpea, sunnhemp or *Sesbania* is recommended. The green-manure crop should be sown during the second fortnight of April and buried when about 50 days old and allowed to decompose for 10 days before sowing of maize.
- When zinc deficiency has been found in the preceding crop, broadcast 25 kg ZnSO<sub>4</sub>·7H<sub>2</sub>O or 15 kg ZnSO<sub>4</sub>·H<sub>2</sub>O at sowing mixed with an equal quantity of dry soil and incorporate into the soil.
- When ZnSO<sub>4</sub> is to be applied in the standing crop, apply 25 kg ZnSO<sub>4</sub>·7H<sub>2</sub>O or 15 kg ZnSO<sub>4</sub>·H<sub>2</sub>O mixed with an equal quantity of dry soil along rows, hoe it into the soil and then irrigate the field.
- Generally, 3-5 irrigations may be required in the monsoon season crop, depending on the rainfall and irrigation water supply.
- For winter maize, it is advisable to keep soil wet with frequent and mild irrigations during the period from mid-December to mid-February to protect the crop from low temperature and frost injury. First irrigation should be applied at 3-4 weeks after germination, and subsequent irrigations at 4-5 week intervals up to mid-March, and thereafter at 1-2 week intervals depending on rainfall and temperature.
- Atrazine and simazine are the two most popular herbicides for maize that check the emergence and growth of a wide spectrum of weeds.
- Pre-emergence application of atrazine or simazine @ 1.0-1.5 kg/ha in 600 litres water give effective control of weeds. The dose can be reduced by 40% in light-textured soils.
- For the control of hardy weeds like *Brachiaria reptans*, *Arachne racemosa* and *Commelina benghalensis*, pre-emergence tank-mix application of atrazine (1.0 kg/ha) + pendimethalin (0.75 kg/ha) has been found to be more effective than atrazine alone.
- In areas where zero tillage is practised, pre-plant application (10-15 days prior to seeding) of non-selective herbicides, viz. glyphosate @ 1.0 kg/ha



or paraquat @ 0.5 kg/ha in 600 litres water, is recommended to kill the existing weed growth.

- Maize borer (*Chilo partellus*) is the borer insect of maize during the monsoon season which can be controlled by the use of synthetic pyrethroids, such as fenvalerate, cypermethrin and deltamethrin or with insecticides such as endosulfan, monocrotophos and carbaryl.
- Shoot fly is a serious pest of spring-sown crop, apply carbofuran or thimet granules in the furrows at the time of sowing to reduce the damage.
- Hairy caterpillars appear in an epidemic form and cause serious damage by feeding on the leaves and tender stems. Spray endosulfan, quinalphos or dichlorvos to control it.
- Termites are also a major problem in many areas. Fipronil granules should be applied @ 20 kg/ha followed by light irrigation.
- Mites attack the young crop or when it is nearing maturity; monocrotophos is recommended for their control.
- Diseases cause an yield loss of about 13%.
- *Turcicum* leaf blight is distributed throughout the country; spray zineb or maneb @ 2.5-4.0 g/litre water (2-4 applications) at 8-10 days interval and plough down the crop debris.
- *Maydis* leaf blight disease also occurs in almost all maize-growing areas; spray of dithane Z-78 or zineb @ 2.4-4.0 g/litre water (2-4 applications) at 8-10 days interval after first appearance of symptoms. Plough down the crop debris.
- Downy mildew is problem in many areas of north-western, central and eastern India. Seed treatment with fungicides like apron 35 ws @ 2.5 g/kg seed is recommended. Young seedlings can be protected from infection by two spays of indofil M-45 at 10 days interval.
- Post-flowering stalk rots occur mainly in Rajasthan, Uttar Pradesh, Bihar and Andhra Pradesh, when the crop enters senescence phase. A mixture prepared with inoculation of biocontrol agent, *Trichoderma* mixed with FYM and covering with wet gunny bags for 10 days should be applied in the furrows before sowing. It is advisable to practice crop rotation with recommended varieties to minimize the incidence.
- *Polysora* rust appears mainly in peninsular India; three sprays of dithane M-45 @ 2.0-2.5 g/litre beginning from first appearance of symptoms at 15 days interval are required.
- Maize can be harvested at physiological maturity.
- For better results, maize (with husk) should be shelled when the moisture content ranges between 15 and 20%.
- Among different maize-based sequence cropping systems, maize-wheat ranks first about 1.8 million ha area, mainly concentrated in rainfed ecologies.
- The other double cropping systems involving maize are: maize-mustard, maize-chickpea, cotton-winter maize etc.
- At New Delhi, quadruple cropping systems developed in the 1970s are: maize-toria/potato-wheat-summer greengram, and maize (green cobs)-radish/turnip-wheat-greengram.



- The QPM is characterized by the presence of balanced amount of amino acids with high content of lysine and tryptophan, and low content of leucine and isoleucine.
- Baby maize is a young finger-like unfertilized cob with 1-3 cm emerged silk preferably harvested within 1-3 days of silk emergence. The desirable size of baby maize is 6-11 cm length and 1.0-1.5 cm diameter. It is a good source of fibrous protein and easy to digest. The sowing of baby maize can be done at any time from April to August.
- Sweet maize/corn is very delicious and rich source of energy, vitamin C and A. It is eaten as raw, boiled or steamed green cob/grains. It is early in maturity, and harvested in 70-75 days during rainy season. It is also used in preparation of soup, salad and other recipes. At harvest, the moisture is about 70% in the grain, and sugar content varies from 11 to 20%.
- Pop maize kernels are relatively small and oval or round in shape. When heated at about 170°C, the grains swell and burst, turning inside out.
- Waxy maize has 100% amylopectin starch compared with 70% in normal maize types.
- High oil maize may contain more than 6% oil as against 3-4 % in normal maize.

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## Sorghum

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Sorghum [*Sorghum bicolor* (L.) Moench], the fifth most important cereal crop on the globe and native to Sub-Saharan Africa, is traditionally grown for grain both as food (Africa and India) and as animal feed (developed countries like USA, China, Australia, etc.) and stalks as animal fodder. The oldest cultivation record dates back to BC 3000 in Egypt. Sorghum is called by various names in different places in the world. In Western Africa, it is called great millet, kafir corn or guinea corn, which represents a connection with corn or millet. It is called *jowar* in India, kaolian in China and milo in Spain. It is the dietary staple of more than 500 million people in 30 countries (Kumar *et al.*, 2011). Sorghum grain is mostly used for food purpose (55%) followed by feed grain (33%). Of late, sweet sorghum is emerging as a potential feedstock for biofuels. Because of its drought-adaptation capability, sorghum is a preferred crop in tropical, warmer and semi-arid regions of the world with high temperature and water stress (Paterson *et al.*, 2009). With the threat of climate change looming large on the crop productivity, sorghum being a drought-hardy crop, will play an important role in food, feed and fodder security in dryland economy.

### AREA, PRODUCTION AND PRODUCTIVITY

#### World

In 2009, sorghum was grown on 40 million ha area in the entire world, producing about 56 million tonnes grain with an average yield of 1,404 kg/ha (Table 4.1). India and Africa account for the largest share (>70%) of global sorghum area, while the USA, India, Mexico, Nigeria, Sudan, Ethiopia and Australia are the major sorghum producers. Globally, the sorghum area declined from 51 million ha in 1980s to 40 million ha in 2009, while the productivity increased from 1,300 kg/ha to 1,400 kg/ha during the same period owing to adoption of improved sorghum cultivars and management practices.

#### India

Unlike in other parts of the world, sorghum in India is cultivated during both rainy (*kharif*) and post-rainy (*rabi*) seasons, mainly as a rainfed crop (92% of the area). The area, production and productivity of sorghum in different states of India are given in Table 4.2. In India, Maharashtra is the largest sorghum



**Table 4.1** Area, production and productivity of sorghum in world (2009)

Continent/country	Area (million ha)	Production (million tonnes)	Yield (kg/ha)
Asia	8.91	9.77	1,096
• India	7.53	7.25	963
• China	0.56	1.68	2,998
Africa	24.23	21.90	904
• Burkina faso	1.65	1.52	920
• Cameroon	0.50	0.60	1,200
• Chad	0.85	0.60	707
• Egypt	0.16	0.88	5,570
• Eritrea	0.25	0.06	236
• Ethiopia	1.62	2.97	1,836
• Mali	1.09	1.47	1,343
• Nigeria	4.74	5.27	1,113
America	5.91	21.06	3,351
• Argentina	0.46	1.81	3,954
• Brazil	0.79	1.85	2,338
• USA	2.23	9.73	4,355
Europe	0.15	0.67	4,451
Australia	0.77	2.69	3,510
World	39.97	57.0	1,404

Source: FAO 2011. <http://faostat.fao.org/site/567/DesktopDefault.aspx?Page ID=567# ancor> verified on December 5, 2011

grower and producer followed by Karnataka, Madhya Pradesh and Andhra Pradesh. It was known as 'great millet' till early eighties with an area of more than 18 million ha. The area has declined drastically from 18.6 million ha in 1970 to 7.53 million ha in 2009; the total production also declined from 9.72 million tonnes to 7.25 million tonnes during the same period. But, the productivity has increased from 522 kg/ha to 963 kg/ha during the same period mainly owing to adoption of improved production technologies by the farmers. The reduction of the area has been mainly in the *kharif* (rainy) season primarily owing to introduction of more remunerative crops like soybean, cotton and maize. *Kharif* sorghum is grown in most of the states, while *rabi* (post-rainy) sorghum is largely confined to contiguous Deccan plateau regions of Maharashtra, Karnataka and Andhra Pradesh. In recent years, sorghum cultivation is gaining popularity among the farmers in rice-fallows of coastal Andhra Pradesh, especially in Guntur and adjoining Krishna and Prakasam districts. The area of sorghum in rice-fallows has increased from 1,000 ha during 2008-09 to >5,000 ha area in 2010-11. The average productivity, however, has also considerably increased (Singh, 2010; Chapke *et al.*, 2011).

### TAXONOMY AND CLASSIFICATION

Sorghum belongs to the tribe Andropogoneae of family Poaceae and sub-family Panicoideae. The genus sorghum is divided into five sections: *Parasorghum*, *Stiposorghum*, *Heterosorghum*, *Chaetosorghum* and *Sorghum*.

**Table 4.2** State-wise area, production and productivity of sorghum in India (2008-09)

State	Season	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
Andhra Pradesh	<i>Kharif</i>	0.12	0.17	1,415
	<i>Rabi</i>	0.16	0.27	1,671
	Total	0.28	0.44	1,563
Gujarat	<i>Kharif</i>	0.12	0.17	1,331
	<i>Rabi</i>	0.05	0.04	860
	Total	0.17	0.21	1,195
Haryana	<i>Kharif</i>	0.08	0.04	506
Karnataka	<i>Kharif</i>	0.24	0.33	1,376
	<i>Rabi</i>	1.14	1.30	1,137
	Total	1.38	1.63	1,179
Madhya Pradesh	<i>Kharif</i>	0.48	0.57	1,193
Maharashtra	<i>Kharif</i>	0.85	1.08	1,270
	<i>Rabi</i>	3.22	2.51	779
	Total	4.07	3.59	881
Odisha	<i>Kharif</i>	0.01	0.01	629
Rajasthan	<i>Kharif</i>	0.58	0.33	577
Tamil Nadu	<i>Kharif</i>	0.20	0.14	715
	<i>Rabi</i>	0.06	0.07	1,185
	Total	0.26	0.21	827
Uttar Pradesh	<i>Kharif</i>	0.19	0.20	1,010
Others	<i>Kharif</i>	0.03	0.02	870
All India	<i>Kharif</i>	2.89	3.05	1,055
	<i>Rabi</i>	4.64	4.19	905
	Total	7.53	7.25	963

Source: *Agricultural Statistics at a Glance, 2010*. Department of Agriculture and Cooperation, Ministry of Agriculture, GOI (<http://agricoop.nic.in/Agristatistics.htm>)

Section *Sorghum* includes annual cultivated forms from Asia and Africa and perennial taxa from southern Europe and Asia.

Three species are recognized:

- *S. halepense* (L.) Pers. (2n=40): A rhizomatous perennial species with creeping rhizomes, pedicellate spikelets deciduous when mature, and up to 25 cm long.
- *S. propinquum* (Kunth) Hitchc. (2n=20): A rhizomatous perennial species with creeping rhizomes, pedicelled spikelets deciduous when mature, sessile spikelets acute to acuminate, lower glume with the keels ending without or with only obscure teeth, leaf blades broad, panicles large and 20–60 cm long.
- *S. bicolor* (L.) Moench: annual taxa cultivated.  
Species *S. bicolor* comprises three subspecies: *bicolor*, *drummondii* and *verticilliflorum*.

Based on mature spikelet types, Harlan and de Wet (1972) divided cultivated sorghum (*Sorghum bicolor* subsp. *bicolor*) into five basic races:



*Bicolor* (grain elongate, sometimes slightly obovate, nearly symmetrical dorso-ventrally, glumes clasping the grain, which may be completely covered or exposed as much as one-fourth of its length at the tip, spikelets pedicellate and persistent); *Guinea* (grain flattened dorso-ventrally, sublenticular in outline, twisting at maturity nearly 90 degrees between gaping involute glumes that are from nearly as long to longer than the grain); *Caudatum* (grain markedly symmetrical, the side next to the lower glume flat or in extreme cases somewhat concave, the opposite side rounded and bulging, the persistent style often at the tip of a beak pointing towards the lower glume, glumes half the length of the grain or less); *Kafir* (grain approximately symmetrical more or less spherical, glumes clasping and variable in length, spikelets sessile and hairy); *Durra* (grain rounded obovate, wedge-shaped at the base and broadest slightly above the middle; glumes very wide, the tip of a different texture from the base and often with a transverse crease across the middle) and 10 hybrid races: *guinea-bicolor*, *guinea-caudatum*, *guinea-kafir*, *guinea-durra*, *caudatum-bicolor*, *kafir-bicolor*, *kafir-caudatum*, *kafir-durra*, *durra-bicolor* and *durra-caudatum*.

### VARIETAL IMPROVEMENT

The real development of hybrids in sorghum became feasible with the discovery of genetic male sterility ( $ms_2$ ) by Stephens (1937) and the subsequent discovery of cytoplasmic male sterility  $ms_{c1}$  (Stephens and Holland, 1954, Doggett, 1988). An early hybrid in the USA was 'RS 610', a cross of combine Kafir 60A (male sterile) with combine 7078 which offered a substantial yield increase over the varieties. In India, while sorghum research was being carried out during pre-independence years, organized sorghum research was initiated in 1962 with the establishment of Accelerated Sorghum and Millet Improvement Project (ASMIP) and later on All India Coordinated Sorghum Improvement Project (AICSIP) in 1969 with 18 main centres spread over in 13 State Agricultural Universities in 11 major sorghum-growing states. First commercial sorghum hybrid CSH 1 was released in 1964 for all India cultivation using the parental line bred in the USA and supplied by the Rockefeller Foundation. Indian sorghum breeding since then steadily gained competence and moved to the vanguard. In 1970, AICSIP was shifted from New Delhi to IARI Regional Station, Hyderabad. In 1972, the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) was established in Hyderabad, which further spurred sorghum improvement research. National Research Centre for Sorghum was established in 1987 at Hyderabad by upgrading IARI Regional Station.

With the release of CSH 1, the first commercial hybrid in 1964, sorghum became the second crop after maize in developing high-yielding hybrids using cytoplasmic genetic male sterility system. Later 25 more hybrids were added for central release for *kharif*. A few more hybrids adapted to specific regions were released at state levels. The hybrids played a major role in pushing up productivity and production, particularly in the case of *kharif* sorghum. Among the *kharif* hybrids, the role played and being played by CSH 1, CSH 5, CSH 6, CSH 9, CSH 14 and CSH 16 needs special mention. While CSH 5 and CSH 6 had a yield potential of 3.4 tonnes/ha, this potential was raised to 4.0 tonnes/ha



in CSH 9 and more than 4.1 tonnes/ha in CSH 16, CSH 23 and CSH 25, with distinctly superior quality grain, and fodder (stover).

Several high-yielding varieties, such as CSV 1 to CSV 20 were also released in various states. Some of these varieties are dual-purpose type. By and large, varieties recorded less acceptability among farmers in *kharif*. Better preference was received for dual-purpose varieties such as CSV 10, CSV 13, SPV 462 and CSV 15 in some restricted pockets. A major advantage of varieties over hybrids was their relative better grain quality and multiple resistance or tolerance against major pests and diseases. The dual-purpose varieties CSV 15, CSV 20 and CSV 23 could establish higher grain and fodder yield potential than potential hybrids released earlier.

Improvement of *rabi* sorghum did not receive as much emphasis and effort as the *kharif* sorghum until the nineties. Six hybrids and five varieties have been hitherto centrally released for *rabi*. The first *rabi* sorghum hybrid CSH 7R and the latest hybrid CSH 19R were released keeping in view the importance of fodder. The *rabi* varieties CSV 8R, CSV 14R, CSV 18 and Swathi, were better received by the farmers than the hybrids CSH 7R and CSH 8R. However, the recently developed hybrids CSH 15R and CSH 19R are more productive, but the acceptability among farmers is not high as they do not want to invest on hybrid seeds during *rabi* (dry season) without irrigation. A list of hybrids and varieties released and recommended for different states is given in Table 4.3.

**Table 4.3** Recommended hybrids and varieties of sorghum for different states

(A) *Kharif* season

States	Areas of adaptation/soil types	Hybrids	Varieties
Maharashtra	Light soils	CSH 1, CSH 6, CSH 14	-
	Medium to heavy soils	CSH 9, CSH 10, CSH 11, CSH 13, CSH 16, CSH 18, CSH 23, CSH 25	CSV 10, CSV 11, CSV 13, CSV 15, PVK 400, PVK 801, SPV 462
Karnataka	Low rainfall areas	CSH 1, CSH 6, CSH 14	SB 1066, DSV 1
	Assured rainfall areas	CSH 5, CSH 10, CSH 13, CSH 16, CSH 25	CSV 10, CSV 11, CSV 13, CSV 15, SPV 462
Andhra Pradesh	Low rainfall areas	CSH 6, CSH 14	CSV 10, CSV 11
	Normal rainfall areas	CSH 5, CSH 9, CSH 10, CSH 11, CSH 13, CSH 16, CSH 18, CSH 23, CSH 25	SPV 462, CSV 10, CSV 11, CSV 13, CSV 15, CSV 17, CSV 20
	Late <i>kharif</i> ( <i>Maghi</i> )	CSH 5, CSH 9, CSH 13	Moti
Madhya Pradesh	Entire state	CSH 5, CSH 9, CSH 10, CSH 11, CSH 13, CSH 16, CSH 18 and CSH 23	CSV 10, CSV 11, CSV 13, CSV 15, CSV 17, CSV 20, SPV 462, Jawahar Jowar 1041

Table 4.3 contd



Table 4.3 contd

States	Areas of adaptation/soil types	Hybrids	Varieties
Tamil Nadu	Madurai district	CSH 1, CSH 14	CSV 11, CSV 15
	Entire state	CSH 5, CSH 6, CSH 11, CSH 13	Co 24, Co 25, Co 26, CSV 15, CSV 13, CSV 17
Gujarat	South Gujarat	CSH 5, CSH 9, CSH 11, CSH 13	CSV 10, SPV 462, CSV 13, CSV 15, GJ 35, GJ 36, GJ 37, GJ 39, GJ 40, GJ 41
	North Gujarat and Saurashtra	CSH 6, CSH 10, SPH 468	CSV 10, SPV 462, CSV 15 CSV 13, GJ 37, GJ 38, GJ 39, GJ 40
Rajasthan	Medium to heavy soils	CSH 1, CSH 5, CSH 6, CSH 9, CSH 10, CSH 11, CSH 13, CSH 14, CSH 16 and CSH 23	CSV 10, CSV 13, CSV 15, CSV 17, CSV 20, CSV 23, Pratap Jowar 1430
Uttar Pradesh	Entire state	CSH 9, CSH 10, CSH 11, CSH 14, CSH 13, CSH 16	Bundela, CSV 10, CSV 11, SPV 462, CSV 13, CSV 15, CSV 17, CSV 20

## (B) Rabi season

States	Soil type	Area of adaptation	Hybrids	Varieties
Maharashtra	Deep soil	Rainfed	CSH 15R CSH 19R	Phule Yashoda, Phule Vasudha, Parbhani Moti, PKV Kranti, M 35-1, CSV 22
	Medium soil	Rainfed	-	Phule Chitra, Phule Maulee, M 35-1
	Shallow soil	Rainfed	-	Phule Anuradha, Phule Maulee, Sel. 3
	Medium-deep soil	Irrigated	-	Phule Yashoda, Phule Vasudha, Parbhani Moti, PKV Kranti, CSV 18
	Medium-Deep soil	Rainfed	-	Phule Uttara (Hurda purpose)
Karnataka	Shallow soils	Rainfed	DSH 4	M 35-1, DSV 4
	Medium-deep soils	Protective irrigations		DSV 5
	Deep soils	Irrigated	CSH 15 R	DSV 5, Phule Yashoda, CSV 18, CSV 22

Table 4.3 contd

Table 4.3 concluded

States	Soil type	Area of adaptation	Hybrids	Varieties
Andhra Pradesh		Early <i>rabi</i> (Rayalseema region)	CSH 15 R	CSV 14R
		Normal <i>rabi</i>	CSH 15 R	M 35-1, CSV 14 R, CSV 216R, CSV 18, CSV 22
		Telangana region	CSH 14 R	SPV 462
		Coastal Andhra (Rice-fallows)	CSH 16, CSH 23, CSH 25, Mahalaxmi 296	—

### THE PLANT

Sorghum is a self-pollinated  $C_4$  plant of Poaceae family. A brief description of various plant parts is discussed here (ICRISAT, 1988).

#### Root

The early temporary root in sorghum is the single radicle of the germinating seedling. The remainder of the fibrous root system develops from lowest node of the stem. Mature roots are adventitious. Sorghum root system could be divided into seminal, adventitious and nodal roots (Maiti, 1996). Seminal roots develop directly from the elongation of the radicle and can easily be distinguished by its continuity with the base of the culm. These roots are mainly responsible for the establishment of seedlings and are reported to survive up to 4-5 days by which time the other roots develop. The adventitious roots develop from the base of the coleoptile. These roots become active at about 30 days of plant age and remain active up to anthesis. The nodal/crown roots develop from the lowest node of the stem 30-40 days after emergence and are heavily branched. These roots are strong and green. Depending on the cultivar, crown-root development may extend to several nodes. Nodal roots are active from anthesis up to maturity and support the stem.

#### Stem

The stem or culm is made up of a series of alternating nodes and internodes encircled by leaf sheaths. Sorghum stems are solid though the centre but may become spongy, with spaces in the pith. The stem measures 0.5 to 5.0 cm in diameter near the plant base and becomes narrower towards peduncle. It grows to a height of 0.5-4.0 m at maturity depending on the cultivar. The nodes appear as a ring at the base of the leaf sheath. A bud is present at each node, except at the flag leaf, and sprouts on alternate sides of the stem. Sometimes these buds develop into auxiliary tillers, while basal tillers are formed at the first node



(House, 1980). Sweet sorghum and certain fodder varieties have juicier and sweeter stem than grain sorghum.

### **Leaf**

Sorghum has four embryonic leaves. The leaves on the main stem vary from 14 to 17 depending on cultivar. Generally, young leaves are erect and the older leaves are curved. Mature leaves may attain a maximum length of >100 cm and a width of 10-15 cm. The terminal leaf is called flag leaf. The leaf sheath is attached to the node and surrounds the internode. The arrangement of leaves on the stem is usually alternate in two ranks on opposite side of the stem.

Leaves are glabrous with smooth leaf margin. The stomata occur on both surfaces of the leaf and there are also lines of motor cells which cause the leaves to roll inwards under drought conditions.

### **Panicle**

The inflorescence of sorghum is a panicle (also known as 'head') with a central rachis from which primary branches arise. The panicle consists of several spikelets in pairs, one of them being sessile and fertile, the other being pedicelled and male or sterile. The size of panicle ranges from 7.5 to 50 cm in length and 4 to 20 cm in width. They may be compact or loose. Sessile spikelet has two glumes of roughly equal length, may be coriaceous (leathery) or chartaceous (papery) at maturity. The lower glume partially envelops the upper one and they may be roughly grouped into ovate, elliptic or obovate shapes. The glumes enclose two florets, the upper being perfect the lower being sterile. The fertile floret has a membranous lemma with a two toothed cleft at the apex. There are three stamens and a single-celled ovary with two long styles ending in plumose stigmas. Certain sorghum varieties regularly produce twin seeds in each spikelet, due to the second floret being fertile.

### **Grain**

Sorghum grain is 'caryopsis'. Grain is a ripened ovary with attached glumes. The grains are pointed at the base and have a slight depression near the end. The grain colour may be white, yellow or brownish-yellow. The pigment is confined to seed-coat layer with the exception of yellow shade, which can be present in the endosperm. Sorghum grain consists of endosperm, pericarp, testa and germ. Twin seeds are also found in some genotypes. The 1,000-grain weight varies from 25 to 30 g.

## **GROWTH STAGES**

The growth period of sorghum has three distinct phases: vegetative, floral initiation and grain-filling.

### **Growth stage 1**

It consists of seedling stage and starts from the date of seedling emergence to the onset of the reproductive phase (panicle-initiation stage). Most of the leaves initiate during this stage. The duration ranges from 33 to 45 days.

**Growth stage 2**

It is panicle-development stage and starts from panicle initiation (PI) to anthesis (or 50% flowering). The duration ranges from 35 to 40 days. This stage is also paralleled by stem elongation.

**Growth stage 3**

It is grain-filling stage and starts from anthesis to physiological maturity. Formation of the black layer at the base of grain signals the end of this stage. The duration usually ranges between 40 and 45 days, depending on genotype and environment.

According to Maiti (1996) and Rao *et al.* (2004) growth and developmental stages in sorghum can be numbered from 0 to 9 (Table 4.4).

**Table 4.4** Developmental and physiological growth stages of sorghum and approximate time required for each stage

Developmental stage	Identifying characters	Days after emergence	Growth stage
0	Seedling emergence: Coleoptile leaf visible	0	-
1	Three leaf: collar or third leaf visible	5-6	1
2	Five leaf: collar of fifth leaf visible	15-16	1
3	Panicle initiation: growing point differentiation	30-35	1
4	Flag leaf: final leaf visible	40-50	1
5	Boot: head extended into flag leaf sheath	50-60	2
6	Half bloom (50% flowering): half of plants at bloom stage	60-65	2
7	Soft dough: milky stage	75-80	2
8	Hard dough: milky stage converted hard dough stage	90-95	3
9	Physiological maturity: black hilar layer formed at the hilar region of the seed	100-105	3

Source: Maiti (1996) and Rao *et al.* (2004)

### SORGHUM ECOSYSTEMS

Sorghum is a warm temperate and tropical cereal. It is adapted to latitude ranging from 40°S to 45°N of the equator. In India, the *kharif* sorghum areas extend from 9°N to 25°N latitudes while the *rabi* sorghum area confines to the narrow belt of 14°N to 21°N latitudes (Sivakumar and Virmani, 1982). It is grown in the semi-arid tropics right from sea-level to an altitude of 3,000 m in variable rainfall areas. The agro-ecological situations of major sorghum-growing areas of India is given in Table 4.5. Sorghum requires warm conditions but can be grown under a wide range of soil and environmental conditions. It can tolerate moisture stress and high temperatures better than any other crops. The



**Table 4.5** Agro-ecological situations of major sorghum-growing areas of India

Location	State	Water-holding capacity (mm)	Latitude (°N)	Longitude (°E)	Average rainfall (mm)	
					Kharif	Rabi
Akola	Maharashtra	120-280	20.50	77.17	680	60
Parbhani	Maharashtra	120-280	19.50	76.75	700	70
Rahuri	Maharashtra	120	19.38	74.65	360	70
Solapur	Maharashtra	140-190	17.75	75.50	400	100-130
Jodhpur	Rajasthan	190	26.75	72.75	310	-
Kota	Rajasthan	220	25.0	76.50	620	-
Shajapur	Madhya Pradesh	90-200	23.50	76.25	840-900	-
Indore	Madhya Pradesh	200	22.67	75.75	820	-
Bhopal	Madhya Pradesh	90-170	23.50	77.42	1,040	-
Ujjain	Madhya Pradesh	200	23.42	75.50	860	-
Dhar	Madhya Pradesh	200	22.50	75.25	840	-
Dharwad	Karnataka	190-230	15.47	75.02	420	90
Belgaum	Karnataka	190-230	16.33	74.75	870	-

Source: Murthy *et al.* (2007)

average temperature in the rainy season varies from 28 to 31°C. In post-rainy season, it ranges from 22 to 29°C. Among sorghum-growing areas in India, maximum temperature can reach as high as 45°C at Jhansi, while it could be as low as 8°C during November at Indore. The minimum temperature for seed germination ranges from 7 to 10°C. Soil temperature of 17-18°C has been reported highly satisfactory for sorghum seedling emergence. Higher temperature (>35°C) may result in poor emergence and seedling growth. The crop requires 26-30°C temperature for good growth. Low temperature (below 13°C) at bloom stage during *rabi* adversely affects seed setting (Quinby *et al.*, 1973). Sorghum is best adapted to areas having an average annual rainfall between 450 and 650 mm. Sorghum stays 'dormant' during extreme drought stress and recovers with rains and the yields are more stable under stressful climate than that of maize (Rao *et al.*, 2004). In India, the primary *kharif* sorghum production zone comprises 22 districts with about 2.26 million ha. Out of these districts, 11 districts belong to Maharashtra with annual rainfall ranging from 300 to 750 mm. The remaining districts are in Rajasthan, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu. These areas are characterized by low annual rainfall from 200 mm to 500 mm. *Rabi* sorghum is a post-rainy season crop, depending on residual soil moisture and very little occasional rainfall during the crop-growth period.

### SOILS

Soils with clay loam or loam texture, having good water-retention capacity are best suited for sorghum cultivation. In India, rainy-season sorghum is grown in Vertisols and Vertic soil types, Entisols, Inceptisols, and to a certain extent



in Alfisols. Post-rainy sorghum is largely confined to Vertisols (Tandon and Kanwar, 1984). Alfisols are light-textured and shallow with poor nitrogen and phosphorus content but rich in non-exchangeable potassium. These soils are mostly present in Andhra Pradesh and Karnataka and are suitable for *kharif* sorghum. Crust formation on surface is a serious problem in these soils. Vertisols (black soils) are predominant in the states of Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, Gujarat and Madhya Pradesh. These soils are clayey (40 to 70% clay) with varying depths from shallow to deep and suitable for both rainy and post-rainy season sorghum cultivation. In general, stored available soil moisture of about 90 to 100 mm is required to sustain a *rabi* sorghum crop. The amount of moisture stored in the soil depends on its depth and the rainfall received during the rainy season (Table 4.6). If winter showers are received, a good crop can be harvested on soils with less moisture-storage capacity.

**Table 4.6** Available soil moisture in different soil types

Soil type	Soil depth (cm)	Available soil moisture (mm)
Very shallow	7.5	15–20
Shallow	22.5	30–35
Medium deep	45.0	60–65
Medium deep	60.0	80–90
Deep	90.0	140–150
Very deep	120.0	160–180

Source: MPAU Bulletin, 1981

### GROWING SEASONS

In India, sorghum is grown in two distinct seasons, *kharif* (rainy) and *rabi* (post-rainy) seasons. However, in some parts of Andhra Pradesh it is grown as 'maghi' (late *kharif*) and also as late *rabi* (summer) in Tamil Nadu. The *kharif* sorghum is grown during July-October, while *rabi* sorghum is grown during October-February. There is an emerging trend for summer cultivation of sorghum as an irrigated crop in Nanded and Pune districts of Maharashtra and Bidar district of Karnataka.

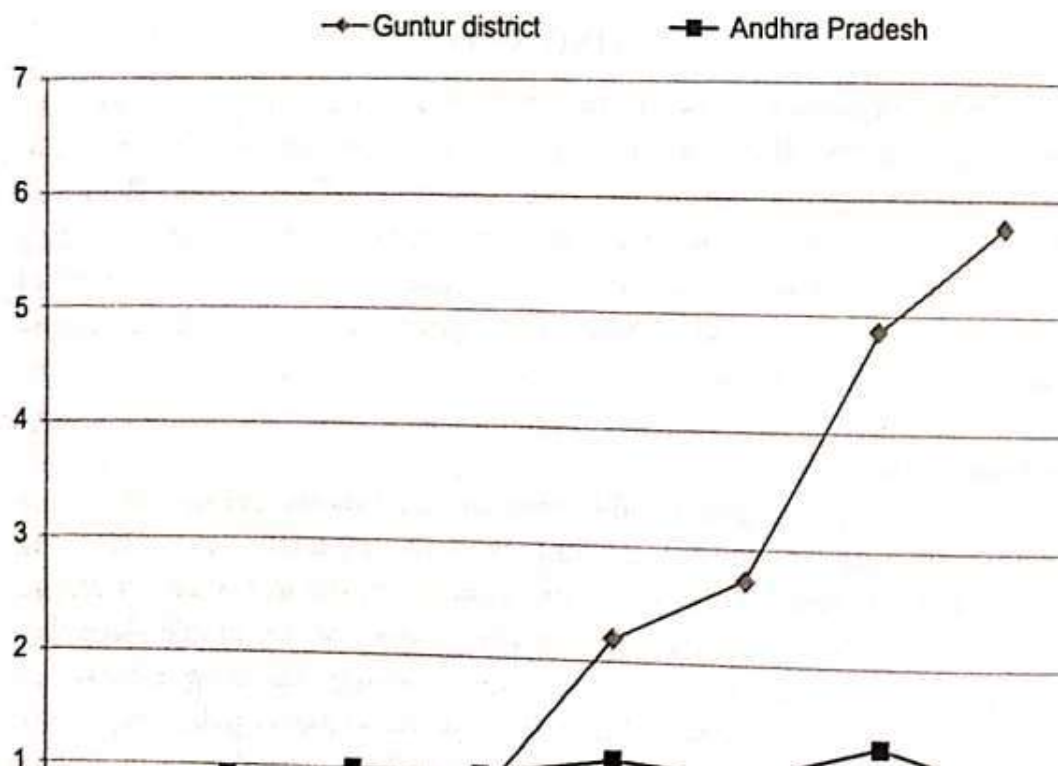
#### Sorghum in rice-fallows

In recent years, sorghum cultivation in rice-fallows during late-*rabi* is gaining popularity in coastal Andhra Pradesh, especially in Guntur and adjoining Krishna and Prakasham districts due to insufficient water for second crop of rice. The farmers plant sorghum after harvest of rice in mid-December under zero-tillage to utilize the residual soil moisture. The crop is harvested during the first week of April. Previously, in rice-fallows pulses especially blackgram and greengram were the major crops of the coastal areas of Andhra Pradesh; wherein blackgram/greengram seeds were broadcast in standing crop of rice (before rice harvest) to utilize the residual soil moisture. However, due to infestation of yellow mosaic virus, weed problems especially parasitic weed *Cuscuta campestris*, and delayed sowing of pulses due to late harvesting of rice crop, the productivity of pulses declined considerably. The farmers of the coastal area having assured irrigation facilities have now shifted to maize and those



with limited irrigation to sorghum. Sorghum in rice-fallows is now grown in more than 5,000 ha area under zero tillage with an average productivity of 5.7 tonnes/ha (Fig. 4.1), which is the highest in the country (average yield is < 1.0 tonne/ha). Sorghum also requires fewer inputs such as nutrients and plant-protection measures as compared to maize. Farmers of the area are harvesting up to 6-7 tonnes/ha sorghum grains depending up on management practices. Keeping in view the scarcity of irrigation water in future, the area under sorghum is expected to increase.

After harvesting of *kharif* transplanted rice during the first week of December, sorghum is sown under zero-tillage to utilize the residual soil moisture. The sowing is done manually in rows 40 cm apart at a spacing of 15 cm. The seeds are sown at 4-6 cm depth by making a hole with wooden stick and putting 2-3 seeds in each hole. For effective weed control, tank mixed application of paraquat + atrazine (0.50+0.75 kg/ha) is done one day after sowing. No fertilizer is applied at sowing. However, 30 days after sowing (at first irrigation), 75 kg N and 60 kg  $P_2O_5$ /ha are applied near the individual plant. At 60 days after sowing (at second irrigation), 75 kg/ha N and 60 kg/ha  $K_2O$ /ha are applied. Among sorghum cultivars, hybrids are preferred over varieties as the farmers are interested only in grain. Among different hybrids, CSH 25, CSH 16, Kaveri 6363, Mahalaxmi 296, Sudama 333, NSH 27 and SBSH 151 have been found promising.





## SEEDBED AND SEEDING

### Seedbed

A proper seedbed preparation is essential for uniform seedling emergence and early establishment of sorghum. It also improves soil aeration and moisture retention, and helps in weed control. Deep ploughing once with mould-board plough during off-season, especially during summer months, is essential to control perennial weeds and insect-pests. In red soils, deep ploughing mixes bottom clay with top layers and thus improves moisture-holding capacity and wetting depth. Deep tillage also conserves soil moisture by providing more opportunity time for water to infiltrate into the soil. Vijayalaxmi (1987) reported 39% increase in sorghum grain yield owing to off-season tillage. After receipt of pre-monsoon showers, the deep ploughed lands need to be cultivated twice with disc harrow followed by rotovator once to break the clods, to control perennial weeds and to incorporate crop residues.

### Sowing

*Time of sowing:* In tropical climates, the onset of monsoon, rainfall pattern, cultivar duration and seedling pests make the planting time an important factor (Dogett, 1988). *Kharif* sorghum should be sown from the onset of monsoon over a period of two weeks. It generally coincides with first fortnight of July. Timely planted crop escapes the damage due to seedling pest 'shootfly' and midge. Pre-monsoon dry sowing a week before the onset of monsoon has also been reported beneficial (Rana *et al.*, 1999).

Sowing time for *rabi* sorghum depends on rainfall pattern of the preceding *kharif* season and moisture content of soil. The optimum sowing time varies from third week of September to first week of October. Planting too early invites heavy infestation of shoot fly and delay in planting results in yield reduction due to moisture stress at grain-filling stage. The planting time can be conveniently adjusted if supplemental irrigations are available.

*Seed rate, spacing and sowing depth:* In *kharif* sorghum, a density of 1.80 lakh plants/ha (18 plants/m<sup>2</sup>) is the optimum plant population to attain maximum yield. A seed rate of 8-10 kg/ha depending on the boldness of seed is recommended. The seeds should be sown in rows 45 cm apart at an intra-row spacing of 12 cm.

During *rabi* under receding soil-moisture conditions, a population of 1.35 lakh plants/ha is optimum. However, under irrigated or assured soil-moisture conditions, higher plant population of 1.85 lakh/ha is recommended. The optimum seed rate is 8-10 kg/ha. Moisture availability is a key consideration in deciding row spacing and plant population. The spacing should be 45 cm × 15 cm for rainfed crop and 45 cm × 12 cm for irrigated crop. Seed should be treated with azotobacter/azospirillum @ 250 g/10 kg seed.

Sorghum is very sensitive to seeding depth. Seeds should be sown at a depth of 3-4 cm for better seedling emergence. Sowing deep > 4 cm may cause poor seedling emergence and vigour. Sowing too shallow < 1.5 cm may cause poor rooting and therefore lodging of the mature crop.



### Thinning

Maintaining optimum plant population (thinning) is a very important operation in sorghum cultivation. Plant-to-plant distance in a row should be kept 12-15 cm by thinning out extra plants at 2 stages. First thinning should be done at 10-15 days after emergence and second, when the crop is 25-30 days old. All the diseased and insect-infested plants should be removed while thinning.

### NUTRIENT MANAGEMENT

Adequate and balanced nutrition is required for proper growth and development of sorghum plant. Shrotriya (1998) reported that balanced application of NPK caused an increase in sorghum yield up to 122% in India. Many factors are involved in determining the mineral requirement of sorghum (Maiti, 1996).

- Amount of available and residual mineral elements in soil
- Physico-chemical properties of soil
- Availability of soil moisture
- Yield and end-product desired

Sorghum is generally grown under less favourable conditions and meagre amounts of fertilizers are applied. The average per hectare use of fertilizer in sorghum was 47.5 kg/ha (29.2 kg/ha N, 14.2 kg/ha  $P_2O_5$  and 4.1 kg/ha  $K_2O$ ) as compared to 60.2 kg/ha in maize, 119.1 kg/ha in paddy and 136.7 kg/ha in wheat (FAO, 2005). There is a widespread deficiency of nitrogen, phosphorus and zinc under both rainfed and irrigated conditions. Cultivars producing large amounts of biomass remove greater quantities of soil nutrients. Sorghum crop producing 5.5 tonnes/ha grain removes a total of 335 kg nutrients (149 kg N + 61 kg  $P_2O_5$  + 125 kg  $K_2O$ )/ha from soil. High-yielding varieties of sorghum remove 22 kg N, 9 kg  $P_2O_5$  and 30 kg  $K_2O$  to produce 1.0 tonne of grain (Tandon and Kanwar, 1984). Sorghum crop yielding approximately 8 tonnes of grain/ha removes about 250 kg N, 40 kg  $P_2O_5$ , 160 kg  $K_2O$ , 45 kg Mg, 40 kg S/ha from soil (Maiti, 1996). Nutrients removed by sorghum hybrid 'CSH 5' in Alfisols under rainfed conditions is given in Table 4.7.

**Table 4.7** Nutrients removal by rainfed hybrid sorghum

Nutrients	Grain yield (tonnes/ha)	Nutrient kg or g/ha
N	4.4	78 kg
$P_2O_5$	4.4	35 kg
$K_2O$	4.4	117 kg
Ca*	2.6	28 kg
Mg*	2.6	17 kg
Fe	4.4	705 g
Mn	4.4	447 g
Zn	4.4	132 g
Cu	4.4	37 g

\*Vertisols (CSH 1) (Lakhdive and Gore, 1978)

### Nitrogen

Nitrogen is the most important abundant mineral nutrient required for sorghum growth. Only about 50% of the N applied to soil is taken up and used by plants (Maiti, 1996). The rest is lost by ammonia volatilization or denitrification or is immobilized in soil. The young plants accumulate relatively high concentration of N and the N content decreases in the various plant parts with age. Most of the plant N is absorbed during the vegetative and by early



grain-filling stages. Plants deficient in N are stunted and older leaves turn pale green to pale yellow. The stem tends to be thin and spindly. The results from a study with  $^{15}\text{N}$  labeled urea at the ICRISAT, revealed that sorghum recovered 62.5% of added N in the Alfisol and 55.0% in the Vertisol. About 27.1% of applied N was distributed in the Alfisol profile and 38.6% in the Vertisol profile, accounting to 89.6% and 93.6% N by the soil + crop system. In Alfisols, crop recovery of N varied from 46.3% to 51.1% as N levels increased from 40 to 160 kg N/ha. At the highest N level tested, soil + crop system could account for 78.9% of added N, as compared to 93.2% at 40 kg N/ha. Although considerable fertilizer N was present in the soil profile after the harvest of rainy-season sorghum, this residual N was of limited value either for safflower grown in the post-rainy season or for sorghum grown in the following rainy season (Morghan *et al.*, 1983). The response (kg grain/kg nitrogen applied) of rainfed sorghum to optimum or near optimum levels of N during the rainy season was 21.7 kg in Alfisols, 18.32 kg in Vertisols, 11.9 kg in Mollisols and 20.15 kg in Entisols (Tandon and Kanwar, 1984). A significant positive interaction between nitrogen and moisture is well established in sorghum and this interaction is stronger in an Alfisol than in a Vertisol (Kanwar, 1978).

To obtain good yield, a dose of 80-100 kg N/ha is generally recommended for high yielding *kharif* sorghum cultivars. For *rabi* sorghum, inorganic fertilizers should be applied based on soil types and moisture conditions (Table 4.8).

### Phosphorus

There is widespread deficiency of phosphorus in soils of semi-arid tropics. It is estimated that only about 10-15% of the P added to the soil is absorbed by plants and remaining 90% become unavailable in the soil by adsorption or fixation by various soil fractions. Phosphorus accumulates extensively in the kernels (as phytin). Phosphorus-deficiency symptoms appear first on the older leaves with purple pigmentation and progress upwards. Excess P can interact with other nutrients (especially, Fe, Zn and Cu) and depress plant growth by causing deficiency of other plant nutrients. The response of phosphorus (kg grain/kg  $\text{P}_2\text{O}_5$  applied) varies with soil types: Alfisols 17-32 kg > Entisols 11-34 kg > Vertisols 7-27 kg. In post-rainy crop, a response of 11 kg grain/kg  $\text{P}_2\text{O}_5$  was obtained in Vertisols. Vertisols may require higher P application than other soils because of their high clay content and greater reactive surfaces/components (Rao and Das, 1982). Apart from soil types, response to P is strongly affected by the yield potential of the cultivars, level of N applied, available soil P and favourable environment. The residual response of P applied to sorghum on succeeding wheat crop is small and not consistent (Tandon and Kanwar, 1984). In general, 40-50 kg  $\text{P}_2\text{O}_5$ /ha is recommended for rainfed *kharif* sorghum and

**Table 4.8** Recommended dose of nutrients for *rabi* sorghum

Area of adaptation/soil type	Nutrients (kg /ha)		
	N	$\text{P}_2\text{O}_5$	$\text{K}_2\text{O}$
<i>Rainfed</i>			
• Shallow	25	-	-
• Medium	40	20	-
• Deep	60	30	-
<i>Irrigated</i>			
• Medium	80	40	40
• Deep	100	50	50



20-30 kg/ha for *rabi* sorghum grown in medium and deep soils. In irrigated *rabi* sorghum, 40-50 kg  $P_2O_5$ /ha is recommended.

### Potassium

Adequate potassium content in plants is associated with higher tolerance to drought and higher resistance to frost and salinity damage, and resistance to fungal diseases. Potassium deficiency symptoms appear first on older leaves with marginal yellow chlorosis, and brown necrosis. Potassium-deficient plants have weak stalks and are prone to lodging. Most of the plant K is absorbed by the grain-filling stage. Potassium deficiency may not be a serious problem for sorghum. However, recent studies indicated an application of 40-50 kg  $K_2O$ /ha in rainfed *kharif* and irrigated *rabi* sorghum.

### Method and time of fertilizer application

Nitrogen should be applied as close to planting as possible. Nitrogen utilization by sorghum plant is quite rapid after the plant reaches five-leaf stage, with 65-70 % of the total N accumulating by the bloom stage of growth (Cothren *et al.*, 2000). Apparent N recovery also markedly improves when N is applied in 2 or 3 splits in a high rainfall year (Venkateswarlu *et al.*, 1978). Sorghum yields are adversely affected if the dose of N at planting is either reduced to less than 50% of the total dose or the top-dressing is delayed beyond the flower primordia initiation stage (Tandon and Kanwar, 1984). For good yield, half amount of nitrogen and full amount of phosphorus and potassium should be applied at planting and placed below the seed. Remaining N should be applied at 35 days after sowing as side-dressing.

### Micronutrients

Among micronutrients, deficiency of zinc (Zn) is widespread in sorghum-growing areas. Of the 251,660 soil samples analysed for micronutrients, 49% were deficient in Zn and 12% in Fe content (Singh, 2001). Zinc deficiency appears on younger leaves with broad yellow or white bands between the margins and mid-vein in lower half of leaf. Most Zn in sorghum is taken by the early grain-fill stage. Next to Zn, iron (Fe) nutrition to *jowar* or sorghum has importance in some soils. Sorghum is sensitive to iron stress and is less efficient in its absorption and translocation. Fe-deficiency symptoms appear on young leaves with yellow or white interveinal chlorosis. Since Fe uptake decreases with increased  $CaCO_3$  content of the soil, the problem of Fe deficiency is more on calcareous soils. Genotypes differ in their response to Zn and Fe deficiencies. Experiments conducted under All India Coordinated Sorghum Improvement Project (AICSIP) revealed that deficiency of Zn and Fe can be corrected either through soil application of respective sulphate forms or through foliar application (Table 4.9).

### Biofertilizers

A biofertilizer is a substance which contains living microorganisms which, when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability

**Table 4.9** Effect of micronutrients on grain and dry fodder yield of sorghum

Treatment	Grain yield (kg/ha)					
	Coimbatore	Parbhani	Akola	Dharwad	Surat	Mean
RDF+ZnSO <sub>4</sub> 25 kg (Soil appl.)	1,833	2,737	3,178	2,462	3,045	2,651
RDF+FeSO <sub>4</sub> 25 kg (Soil appl.)	1,502	2,312	3,114	2,862	3,491	2,656
RDF+0.2%ZnSO <sub>4</sub> Foliar spray at 15 and 30 DAS	1,730	2,328	2,609	2,289	2,955	2,382
RDF+0.5%FeSO <sub>4</sub> Foliar spray at 15 and 30 DAS	1,553	2,197	2,525	2,466	3,024	2,353
RDF+ZnSO <sub>4</sub> 15 kg (Soil appl.)+0.20% as foliar spray at 15 and 30 DAS	1,936	2,662	3,136	2,882	2,826	2,689
RDF+FeSO <sub>4</sub> 15 kg (Soil appl.)+0.50% as foliar spray at 15 and 30 DAS	1,562	2,009	3,093	2,598	2,971	2,447
RDF+soil application of 15 kg ZnSO <sub>4</sub> + 15 kg FeSO <sub>4</sub>	1,636	2,793	4,798	2,953	3,676	3,171
RDF+ foliar application of 0.20% ZnSO <sub>4</sub> +0.50% FeSO <sub>4</sub>	1,698	2,036	2,925	3,184	3,367	2,642
RDF alone	1,438	1,847	2,883	2,939	2,868	2,395
• Mean	1,567	2,252	3,072	2,509	3,028	2,486
• CD (P=0.05)	160	437	643	355	228	482
• CV%	5.94	11.3	12.2	8.24	4.38	15.1

RDF, Recommended dose of fertilizer; soil appl., soil application; DAS, days after sowing

Source: AICSIP, (2010-11)

of primary nutrients to the host plant (Vessey, 2003). Biofertilizers add nutrients through nitrogen fixation, solubilizing phosphorus, and stimulating plant growth through the synthesis of growth-promoting substances. Biofertilizers can be expected to reduce the use of chemical fertilizers and pesticides. Through the use of biofertilizers, healthy plants can be grown while enhancing the sustainability and health of soil. Biofertilizers form an important component in the integrated nutrient management. A number of biofertilizers, viz. *Azotobacter*, *Azospirillum* etc., are now commercially available for cereals.

#### **Integrated nutrient management**

Importance of the use of organic sources of nutrients along with chemical fertilizers for maintaining soil health has been emphasized by Prasad (2000).



Combined use of inorganic and organic manures improves physical and chemical properties of soils (Shashidhar *et al.*, 1995). Application of 75% recommended dose of fertilizer (RDF) + farmyard manure (FYM) + biofertilizer [*Azospirillum* and phosphate-solubilizing bacteria (PSB)] gave significantly higher plant height, dry matter, yield attributes and grain and fodder yields of sorghum, and was on a par with application of 100% RDF through inorganics alone showing 25% saving of nutrients (Gawai and Pawar, 2006; Patil *et al.*, 2008). Incorporation of FYM, wheat straw and *Gliricidia* leaves for 25 or 50% N substitution in conjunction with balanced dose of NPK fertilizers increased infiltration rate, water-stable aggregates and organic matter content in soil. The available N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O status improved after harvest of both the crops owing to integrated nutrient management by the application of 50% recommended dose of fertilizers and 50% N equivalent with FYM to sorghum in *kharif* and recommended dose of fertilizers to wheat in *rabi* than the continuous application of recommended dose of fertilizers to both the crops (Bhonde and Bhakare, 2008).

### WATER MANAGEMENT

Although sorghum is a drought-tolerant crop, it responds to irrigation and is well suited for limited irrigations situation. It is also known as water-sipping crop as it uses water very efficiently. The sorghum performance under deficit irrigation conditions is associated with its great ability to extract water from deep soil layers, shorter growth duration and leaf characteristics more favourable to drought (Farre and Faci, 2004). The water requirement of sorghum is lower compared to other cereals (Table 4.10). Sorghum crop requires 425-

**Table 4.10** Water requirement and water-use efficiency of different cereals

Crop	Effective root zone	Water requirement (mm)	Water-use efficiency (kg/ha-mm)
Rice	Shallow (60 cm)	1,200	3.7
Maize	Deep (120 cm)	625	8.0
Sorghum	Deep (120 cm)	500	9.0
Pearlmillet	Deep (120 cm)	500	8.0

*Source:* Rao and Rana (1987).

610 mm water for getting higher yield (Solaimalai *et al.*, 2001). Roots of mature sorghum plant can extract soil moisture from up to 2 m of soil depth, although higher yields are obtained when moisture is available in the top 76 cm of soil (Cothren *et al.*, 2000). Water availability to plant largely depends on soil texture. Available water capacity in different soils is given in Table 4.11. *Kharif* sorghum is mainly grown under rainfed conditions. Very often rainfed sorghum crop experiences soil-moisture stress when rains

**Table 4.11** Soil texture and available water capacity

Soil texture	Available water capacity (cm/m)
Course sand	2.1 - 6.2
Fine sand	6.2 - 8.3
Loamy sand	9.2 - 10.0
Sandy loam	10.4 - 11.7
Fine sandy loam	12.5 - 16.7
Silty loam	16.7 - 20.8
Silty clay loam	15.0 - 16.7
Silty clay	12.5 - 14.2
Clay	10.0 - 12.5

*Source:* Klocke and Hergert (1990)

fail during the monsoon season. However, the post-rainy season sorghum is grown on residual soil moisture with limited irrigation facilities.

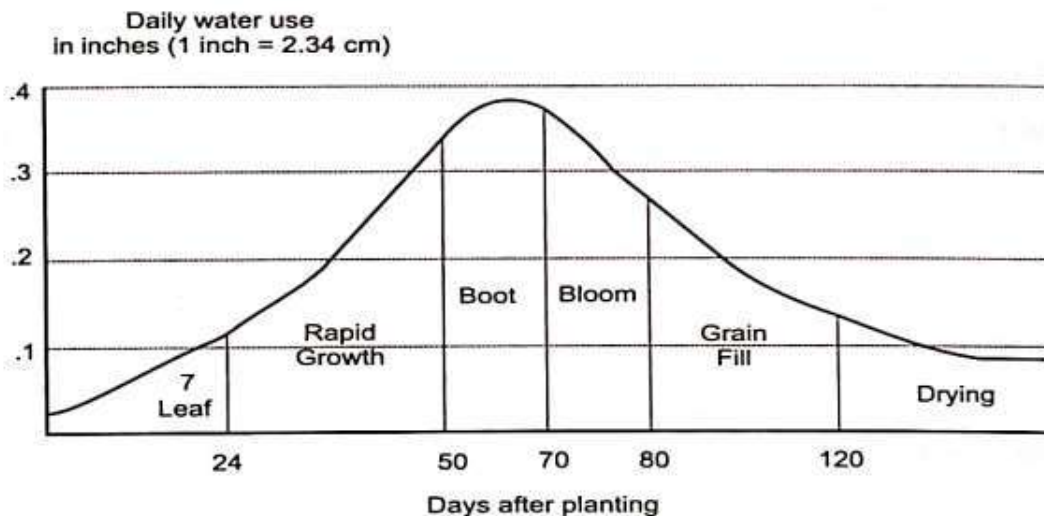
#### Critical stages for irrigation in sorghum

Germination, seedling, flowering and grain-formation stages are critical for irrigation and getting higher yield (Dastane, 1974). The period of 50 to 85 days after sowing (booting to grain-formation stages) is very sensitive to moisture stress (Fig. 4.2).

The critical growth stages of sorghum in relation to water requirement are:

1. Initiation of grand growth stage 20-25 days (DAS)
2. Flag-leaf stage or boot stage 50-55 DAS
3. Flowering stage 70-75 DAS
4. Grain-filling stage 90-100 DAS

In case of limited water availability, it should be given at the flower primordial initiation stage followed by flowering stage.



**Fig. 4.2.** Daily water use (in inches) by sorghum during entire growth period (Source: <http://sanangelo.tamu.edu/agronomy/sorghum/gsprod.htm#seed>)

#### Soil-moisture conservation practices for *rabi* sorghum

**Deep ploughing:** Deep ploughing with mould-board plough followed by 3-4 harrowing during summer (May-June) helps conserve rainwater in deeper soil layers for a longer period.

**Compartmental bunding:** It involves making square or rectangular compartments on the field to retain rain water and to arrest soil erosion in medium deep black soils. After receipt of early rains in June and July, land is harrowed to remove the germinating weeds. Then the compartmental bunds (0.15-0.25 m height) are formed using bullock-drawn bund former. The size of compartments varies from 3 m × 3 m to 4.5 m × 4.5 m depending on the slope.



The cost of compartmental bunding is ₹ 150-300/ha. These bunds are retained till the sowing of *rabi* crop during the second fortnight of September to the first fortnight of October. Compartmental bunds provide more opportunity time for water to infiltrate into the soil and help in conserving soil moisture.

**Ridge and furrow method:** In this system, ridges and furrows are formed across the slope by bullock-drawn plough before monsoon. The height of ridges is around 20 cm and width of furrows is 45 cm. The rainwater is stored in furrows and infiltrates into the soil and helps in conserving soil moisture. Besides, opening of furrows in preceding (*kharif*) legumes (cowpea, mungbean, urdbean, soybean) after every 3rd or 4th row by 'Baliram Plough' conserves soil moisture and improves drainage and increases the productivity of *rabi* sorghum.

*In-situ* moisture-conservation practices, viz. tied ridges and compartment bunding, were found beneficial in conserving soil moisture and gave higher grain yield and net return as compared to flat-bed method (Table 4.12). (Hiremath *et al.*, 2003).

Application of organic mulch (straw of preceding legume crops) in between rows after 3 weeks of sowing helps in conserving soil moisture by reducing evaporation.

**Table 4.12** Effect of *in-situ* moisture-conservation practices on moisture content, grain yield and net returns in *rabi* sorghum

<i>In-situ</i> moisture-conservation practices	Soil-moisture content (cm) in 60 cm profile at flowering	Grain yield (kg/ha)	Stover yield (kg/ha)	Net returns (₹/ha)	Benefit: cost ratio
Flat bed	16.91	1,405	2,399	4,712	0.75
Compartmental bunding	17.35	2,124	3,282	9,491	1.45
Tied ridges	19.69	2,210	3,429	10,055	1.52
LSD (P=0.05)	0.48	281	172	2,040	0.32

Source: Hiremath *et al.* (2003).

## WEED MANAGEMENT

Weeds are a major deterrent in increasing the sorghum productivity, especially during the rainy season, as the crop is sown soon after commencement of monsoon and the temperature is congenial for weed growth. Due to wider row spacing and slow initial growth rate, *kharif* sorghum is heavily infested with weeds. As the crop is mostly grown in rainfed areas where soil moisture and nutrients are the most limiting factors and as the weeds compete for these two resources very much, appropriate weed management would help improve sorghum productivity.

### Major weeds

A mixed population of broad-leaved, grasses and cyperaceous weeds grows with sorghum under different agro-climatic conditions. The most common weed species are discussed here.



*Grasses: Brachiaria ramosa, Chloris barbata, Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Dinebra retroflexa, Echinochoa colona, Eleusine indica, Panicum repens, Paspalum paspaloides, Setaria glauca, Sorghum halepense.*

*Broad-leaved weeds: Acanthospermum hispidum, Achyranthes aspera, Ageratum conyzoides, Amaranthus viridis, Boerhavia diffusa, Celosia argentea, Cleome viscosa, Commelina benghalensis, Convolvulus arvensis, Digera arvensis, Portulaca oleracea, Trianthema portulacastrum, Tribulus terrestris.*

*Sedges: Cyperus rotundus.*

*Parasitic weed: Striga asiatica.*

The critical period of crop-weed competition is 4-6 weeks after seedling emergence.

Weeds compete with sorghum for nutrients, soil moisture, sunlight and space when they are limiting, resulting in reduced yields, lower grain quality and increased production costs. Uncontrolled weeds in sorghum reduce crop yields by 15 to 65% and remove 30-50 kg nitrogen, 5-12 kg phosphorus and 50-74 kg potassium/ha from soil, depending on crop cultivars, nature and intensity of weeds, spacing, duration of weeds infestation and environmental conditions (Mishra and Rao, 2011).

#### **Cultural weed-control measures**

Methods such as good cover crop, viz. cowpea, greengram or blackgram, proper spacing between and with in the rows (45 cm × 15 cm) smother the weed growth. Mulching the soil surface between the crop rows with crop residue materials like straw etc., may prevent the germination of weed seeds and smother the established young weeds. The mulching practices also help in conserving the soil moisture. Crop rotation with trap/catch crops like soybean and cotton, intercropping of sorghum with groundnut, soybean and cowpea and green manuring crops like sunhemp help in reducing the problem of parasitic weed *Striga* in sorghum. Intercropping practices in sorghum not only provide the monitory and land-utilization advantage but also help in smothering the weeds with good crop cover over the land surface.

#### **Mechanical weed-control measures**

Hand hoeing or manual weeding with hand tools such as sickle and *khurpi* or animal-drawn mechanical implements such as blade harrows are still the most common practices performed for weed control in sorghum. Manual weeding by hand tools or inter-row cultivators is used between 3 and 6 weeks after sowing (depending the physical condition of soil during the rainy season). It has been observed that when only dependent on mechanical methods, 2 weedings (first at 20-25 days and second at 40-45 days after sowing) are a must to provide season-long weed control in *kharif* sorghum. If preceded by pre-plant incorporated or pre-emergence or early post-emergence herbicide application, one inter-row cultivation or hand-weeding is sufficient to provide season-long weed control. Mechanical weeding also provides excellent physical conditions to the crop growth by way of soil aeration.



### Chemical weed control

In India, the use of chemicals (herbicides) has revolutionized weed-management practices in crops like wheat, rice, soybean, etc. However, they are seldom used in rainfed crops like sorghum because of the following reasons.

- Sorghum is mostly grown in intercropping system with pulses and oilseeds and selective herbicides are often unavailable.
- Lack of adequate soil moisture in semi-arid regions reduces the efficacy of pre-emergence herbicides.
- Farmers are afraid and believe that the use of herbicides leaves toxic residues in fodder, grain and soil.
- Use of weeds as a source of green fodder for animals in semi-arid regions.
- Farmers think that the herbicides are expensive as they do not include the cost of family labours for weeding.
- Illiteracy among resource-poor farmers of dryland areas and unavailability of suitable herbicides.

However, weed control through selective herbicides as pre-plant incorporation, pre- or post-emergence has been effective in managing weed problems and has also led to increased sorghum production. In rainy-season sorghum, timely weed management only through mechanical methods is many a time risky as the continuous rains do not permit the use of manual/mechanical weeding. Under such a situation herbicidal approach provides effective control of weeds. General herbicide recommendations are in Table 4.13.

**Table 4.13** Herbicide recommendations for sorghum

Herbicide	Application rate (kg a.i./ha)	Product (kg or litre/ha)	Application time	Weeds controlled
Atrazine	0.75-1.0	1.5-2.0	Pre-emergence	Both broad-leaved and grasses
Pendimethalin	1.0	3.33	Pre-emergence	Mostly grasses
Metolachlor	1.0-1.5	2.0-3.0	Pre-emergence	Mostly grasses
2, 4-DEE	0.5-0.75	1.3-2.0	Post-emergence	Mostly broad-leaved and partially sedges

### Precautions to be taken with 2, 4-D

1. 2, 4-D should be applied in grain sorghum when it attains a height of 10-30 cm. Yield reduction occurred when 2,4-D was applied to sorghum at the beginning of tillering and at the beginning of stem elongation (Turk and Tawah, 2002). Symptoms of 2,4-D injury include temporary stalk brittleness, stalk leaning, retarded and abnormal root development and leaf rolling, commonly known as 'onion leafing' or 'buggy whipping'. Affected plants may lodge, break in wind storms and/or have reduced yield. Low volatile ester formulations of 2,4-D generally provide better broad-leaved weed control but are more likely to injure grain sorghum than amine formulations. Also the crops like cotton and soybean are damaged by 2, 4-D drift and volatilization, if planted nearby and spraying is done on a windy day.



2. There should be sufficient soil moisture at the time of applying pre-emergence herbicides.
3. 2, 4-D and atrazine should never be applied in sorghum-based intercropping systems.

#### **Method of herbicide application**

The required quantity of herbicides should be dissolved in water @ 500-600 litres/ha and sprayed uniformly with knapsack sprayer fitted with flat-fan nozzle,

#### **Herbicide resistance**

Sorghum is grown under moisture-stress conditions with low inputs. Under moisture-stress conditions, the efficacy of pre-plant and pre-emergence herbicides, especially on grassy weeds decreases (Tapia *et al.*, 1997). These weeds need to be removed by inter-cultivation or treated with post-emergence herbicides. Therefore, herbicide tolerance through genetic enhancement is a viable option. Herbicide-tolerant crops make it possible to control weeds with non-selective herbicides. Acetolactate synthase (ALS)-inhibitor herbicides, viz. nicosulfuron and nimsulfuron, are widely used to control broad-leaved and grassy weeds in corn (*Zea mays*), but sorghum is susceptible to these herbicides. However, by transferring a major resistance gene from wild sorghum relative, researchers at the Kansas State University, USA, developed a grain sorghum that is resistant to several ALS-inhibiting herbicides, such as Steadfast (nicosulfuron), Accent (nicosulfuron), Resolve (rimsulfuron) and Ally (metsulfuron) (Tuinstra and Al-Khatib, 2007; Tuinstra *et al.*, 2009).

Sorghum roots exude a potent bio-herbicide known as 'sorgoleone', which is produced in living root hairs and is phytotoxic to broad-leaved and grassy weeds at concentrations as low as 10  $\mu$ M (Yang *et al.*, 2004). Herbicide tolerance through transgenic technology is not addressed worldwide because of the opinion of development of 'Super Weed'. It is understood that crops and related wild or weedy plants can and will exchange genes through pollen transfer, if provided with the opportunity, and have been doing so ever since there have been crops and weeds (Harlan, 1982). Transfer of herbicide-tolerant gene to Johnson grass from cultivated sorghum is considered a threat if hybrid develops due to their cross compatibility.

#### **Integrated weed management**

The most promising single approach to weed control in sorghum combines manual, cultural and mechanical methods with herbicides. Herbicides should be used as a supplement at as low a rate as possible. After dry seeding of sorghum during *kharif* season, weeds germinate along with the crop and this early flush of weeds cannot be eliminated by manual or mechanical methods. Also, in the areas where probability of early season rainfall is high, inter-cultivation and manual weeding cannot be used on Vertisols due to their high clay content, which makes them sticky when wet. Under such a situation, use of pre-emergence herbicides like atrazine, metolachlor, pendimethalin, etc. for



removing early weed competition followed by inter-cultures and manual weeding at 30-35 days after sowing for removing later emerging weeds is the most effective weed-management approach.

#### **Management of *Striga* spp. (a parasitic weed)**

*Striga* is a major biotic constraint in the subsistence agriculture and causes considerable crop damage in the semi-arid tropics. *Striga* species (family Scrophulariaceae), known as 'witch weed', are obligate, annual hemi-parasites. They are green plants, capable of photosynthesis, but obtain most of their nourishment from host plants to which they are attached by specialized roots termed haustoria (Maiti *et al.*, 1984). Although there may be as many as 50 species of witch weeds worldwide, *S. asiatica* (*S. lutea*) is the most common in India.

**Losses:** Incidence of *Striga* alone causes a reduction in the grain yield of sorghum up to 75% depending on its intensity and crop-management practices (Rao, 1978). *Striga* reduces the sorghum plant height and shoot and root dry matter. Crop losses of 10-90%, with an average loss of 35% in sorghum have been attributed to *Striga hermonthica* in Nigeria, estimated at US \$ 250 million annually (Parkinson *et al.*, 1986; Lagoke, 1987). *Striga* reduced the sorghum plant height by up to 50%, and shoot and root dry matter by 70% and 50% respectively (Gworgwor *et al.*, 1991). In sub-Saharan Africa, *S. hermonthica* caused 70-100 % crop loss in sorghum, maize and pearl millet (Emechebe *et al.*, 2004).

**Control measures:** Most common control measure, hand pulling, used by the small farm holders, but is only effective when the *Striga* population is low. Although hand-pulling is no solution to a dense infestation, it should be encouraged to prevent new or mild infestations getting worse, and as a part of integrated methods for control of moderate infestations. Plants which are pulled, within 2-3 weeks of the start of flowering, should be taken out of the field and burned so that seeds are not produced and shed from the drying plants. Cattle should not be fed the witch weed plants, as the seeds pass through their alimentary canal and are spread through manure.

Cultural practices such as stubble cleaning in sorghum fields after harvest, crop rotation with non-hosts and with catch crops, mixed cropping without host crops, fertilizer management with high doses of nitrogen as top-dressing, and use of resistant or tolerant varieties help in reducing *Striga* infestation. Whatever the methods, the ideal objective must be to prevent *Striga* seed production—continuing control through and beyond harvest if necessary. Trap crops like cotton stimulate *Striga* germination but are not themselves attacked. Without supply of food from the plant root, the germinated *Striga* seeds die. It is therefore possible to rotate these crops with sorghum to induce suicidal germination (Bekker *et al.*, 2003). Crop rotation with trap/catch crops like soybean and cotton, intercropping of sorghum with groundnut, soybean and cowpea and green manuring crops like sunnhemp help in reducing the problem of parasitic weed *Striga* in sorghum (Gworgwor, 2002; Jost, 1997). Fertilizer, especially nitrogen, tends to reduce, or at least delay, *Striga* emergence and can



be used to further reduce the numbers of parasite that need to be hand-pulled to prevent seeding (Thajrem, 1994; Press *et al.*, 1994).

*Chemical control:* In general, it has proved difficult to find a good selective herbicide to control *Striga* in field crops. Since *Striga* is a broad-leaved plant, use of pre-plant/pre-emergence herbicides such as atrazine, oxyfluorfen show some effect, though not efficient. Post-emergence application of 2,4-D is effective when sprayed on the *Striga* leaves. However, sorghum is vulnerable to stalk twisting and lodging if 2,4-D is sprayed into the leaf whorl; hence proper precautions should be taken while spraying.

### INSECT-PEST MANAGEMENT

Sorghum crop is attacked by number of insect-pests. The key pests and their control measures are given here.

#### Shoot fly

Shoot fly (*Atherigona socatta*) is a major pest of sorghum. Plants up to 4 weeks age are more susceptible to this pest. Maggot feeds on the growing tip causing wilting of leaf and later drying of central leaf giving a typical symptom of 'dead heart'. The damaged plants produce side tillers which again are infested. Early planting with the onset of monsoon is effective in avoiding the infestation of shoot fly during *kharif*; however in *rabi*, planting during 15 September to first week of October is ideal to escape shoot fly damage. Higher seed rate and removal and destroying the 'dead heart' seedlings are the other important management practices. Seed treatment with imidacloprid @ 14 ml or carbosulfan 25 SD @ 200 g/kg seed has also been found effective. Carbofuran 3 G or phorate 10 G as soil application in furrows @ 20 kg/ha before sowing also checks the pest incidence. In case soil application of phorate is not done, damage can be minimized by spraying the seedling 7 and 14 days stages with cypermethrin 2 ml/litre water.

#### Stem-borer

Stem-borer (*Chilo partellus*) attacks plant throughout the growing season. Initially the larvae feed on the upper surface of whorl leaves leaving the lower surface intact. As the severity of the feeding increases, blend of punctures and scratches of epidermal feeding appears prominently. Sometimes 'dead heart' symptoms also develop in younger plants due to early attack. Subsequently, the larvae bore into the stem resulting in extensive stem tunneling. Effective control of the borer can be achieved by removing the stubbles immediately after the crop harvest. Application of carbaryl 4 G or carbofuran 3 G in the leaf whorls @ 8-12 kg/ha at 20 and 35 days after emergence. Biopesticides, viz. *Bacillus thuringiensis* (1 g/litre), NSKE (5%), nimbecidine (5 ml/litre) and *Metarhizium anisopliae* (1 g/litre) were also found effective in reducing stem-borer damage by 5.1 to 24.4% (Jose *et al.*, 2008).

#### Sorghum midge

Sorghum midge (*Contarinia sorghicola*) is one of the most destructive pests to grain sorghum. The insect damages the crop at the blooming stage. The



female sorghum midge deposits a single egg between the glumes of a floret. Larvae destroy the seed, resulting in 'blank' or shriveled seed-coats that often appear discoloured. Heads with severe midge damage appear small and compressed with blank areas. The midge infestation can be prevented by removing the weed Johnson grass and other grasses which serve as alternate hosts. Spraying of carbaryl 50 WP or dusting of carbaryl 10 D at 90% head emergence (prior to flower opening) can effectively check the midge infestation.

#### **Shoot bug**

Shoot bug (*Peregrinus maidis*) is a sporadic pest of sorghum. Under favourable conditions, it produces several generations and causes heavy damage to sorghum. Both the adults and nymphs suck sap resulting in yellowing and drying up of the plant. Heavy infestation at vegetative stage may result in twisting of top leaves and may prevent the formation and emergence of panicles. Application of carbaryl 3 G @ 8 kg/ha in the leaf whorls can effectively check the incidence of the pest. Spraying 5% neem-seed kernel suspension acts as a repellent. Spraying 5% extract of *Vitex* leaves controls the nymphs and adults.

#### **Headbug**

The headbug (*Calocoris angustatus*) infests on the panicle and feeds mainly on the developing seeds and to lesser extent on other panicle parts and causes economic damage by reducing the grain weight, seed quality and viability. Grain mold damage is also severe in bug-affected panicles. Application of carbaryl 50 SP @ 3.0 kg/ha as spray or carbaryl 5 D @ 20 kg/ha as dust to panicles once at pre-bloom and once at milk stage can effectively check the infestation.

#### **Aphids**

Aphids have piercing, sucking mouth parts that they use to suck juices from plant tissue, causing stunted plant growth. Aphids inject a toxin along with saliva into plant tissue, causing a yellowish spot to develop around the point of feeding. Such damaged tissue quickly results in a reddish colour on the leaf surface. These reddish areas gradually enlarge as the aphid colonies on the underside of leaves increase in numbers. Eventually, feeding causes the leaves to start browning at the outer edges and ultimately to die. Attack during boot stage may result in poor panicle exertion. Spraying of metasystox 35 EC @ 1 litre/ha in 500 litres water effectively controls aphids.

#### **Mite**

Mites (*Oligonychus indicus*) suck up the plant sap from leaves first on the under surface of the functional leaves and the infested area initially are pale yellow, but later turn to radish or brownish on the upper leaf surface. Spraying of kelthane 35 EC or monocrotophos 35 EC or dimethoate 35 EC @ 1 litre/ha in 500 litres water has been found effective.

#### **Management of stored grain insect-pests**

The important sorghum storage pests may be classified as per Babu and Prasad (2011).

**Internal feeders:** Rice weevil (*Sitophilus oryzae*), lesser grain borer (*Rhizopertha dominica*), Angoumois grain moth (*Sitotroga cerealella*).

**External feeders:** Khapra beetle (*Trogoderma granarium*), red flour beetle (*Tribolium castaneum*, *T. confusum*), saw toothed grain beetle (*Oryzaephilus surinamensis*), rice moth (*Corcyra cephalonica*), tropical warehouse moth (*Ephestia cautella*), Indian meal moth (*Plodia interpunctella*) and grain mite (*Acarus siro*).

At harvest, sorghum grain contains 20-28% moisture depending on season and weather conditions (Babu and Prasad, 2011). High moisture content in grain during storage offers congenial environment for storage pest attack. Sun drying and use of mechanical dryers can be opted to bring down the moisture content up to 10-12% before grain storage. Fumigation of stored grain either shed fumigation (entire store house or godown) or cover fumigation (only selected blocks or bags) is desirable depending on the intensity of pest attack.

### DISEASES AND THEIR MANAGEMENT

There are more than a dozen of foliar and panicle diseases in sorghum, of which few are important and listed in Table 4.14.

**Table 4.14** Sorghum diseases, identification keys and their control measures

Disease	Casual organism	Field identification key	Control measures
<b>Foliar diseases</b>			
Anthracnose	<i>Colletotrichum sublineolum</i>	Small circular lesions on the mid-rib speckled with black dots	Use of clean seed, destroying plant refuses, crop rotation, removal of host weed plants like Sudan grass, Johnson grass.
Downy mildew	<i>Peronosclerospora sorghi</i>	Appearance of vivid green and white stripes on leaves and white patches of oospores. Whole leaves may become chlorotic and plants usually fail to exert panicles.	Deep ploughing before planting to destroy oospores. Rouging of infected plants. Seed dressing with metalaxyl/ Ridomil 25 at 1 g ai/kg seed.
Rust	<i>Puccinia purpurea</i>	Ruptured pustules releasing red to brown powdery masses from leaf	Use clean seed, crop rotation, destroying of plant refuses, Spraying of dithane M 45 @ 0.2% thrice at 10 days intervals starting at 30 days crop stage.
Zonate leaf spot	<i>Gleocercospora sorghi</i>	Circular lesions with concentric banding	Use clean seed, crop rotation, destroying of

Table 4.14 contd



Table 4.14 concluded

Disease	Casual organism	Field identification key	Control measures
		formed out of fungal growth	plant refuse
<b>Panicle diseases</b>			
Grain mold	A complex of several fungi. Major being <i>Fusarium moniliforme</i> and <i>Curvularia lunata</i>	The infected grains are soft, powdery, with moldy growth of pink, white or black colour.	Avoid cultivars that are likely to mature in heavy rains. Harvesting of panicles at physiological maturity and artificial drying in community dryer. Spraying of fungicides (captan 0.30%, tilt 0.20 %) or bioagents (fluorescent <i>Pseudomonas</i> 10 <sup>7</sup> cfu/ml) on panicles reduces mold incidence and improves seed quality.
Ergot/sugary disease	<i>Sphacelia sorghi</i>	Droplet of sticky liquid exudes from the florets	Ensuring synchrony of flowering (A and R lines) in seed production plots. Early sowing, removal of collateral host from the field bunds. Mechanical removal of sclerotia from seeds. Two spray of 'Tilt' 25% EC @ 0.2% starting from flowering at 10 days interval
<b>Smut</b>			
Loose smut	<i>Sporisorium cruenta</i>	Individual grains replaced by small cream to brown sacs that ruptures soon after head emergence	Use clean seed free from smut sori to reduce the field incidence. Removal and destruction of smutted panicles from the field. Seed dressing with sulphur @ 4 g/kg or Thiram 75 @ 3 g/kg seed to control seed-borne infections in loose and covered smuts.
Covered smut	<i>S. sorghi</i>	Individual grains replaced by small sacs that persists up to threshing	
Head smut	<i>S. reilianum</i>	Panicle partially or completely converted into a large whitish sac	
Long smut	<i>Tolyposporium ehrenbergii</i>	Few individual grains replaced by long white-cream fungal sacs	

Source: Das (2011)

## HARVESTING AND THRESHING

Most of the grain sorghum hybrids and varieties take around 110-120 days to mature. Crop should be harvested immediately after maturity. Timely harvest reduces the risk of losses due to grain shatter or lodged heads or damage due to birds, moulds or sprouted kernels and unfavourable weather. The right stage for harvest is when grains have become hard and firm having less than 25% moisture. The best stage to harvest sorghum is when the plants reach the physiological maturity, which can be determined by the black (dark) spot at the bottom of the grain. Harvesting at physiological maturity saves about 7 to 10 days time in the duration and facilitates timely sowing of the sequence crop in the double cropping areas. Dwarf cultivars are harvested by cutting the earheads first and the stalks later. The stalks (stover) are cut after a week, allowed to dry and then stacked. In the case of tall varieties, the stems are cut at 10 to 15 cm above-ground level and afterwards the earheads are separated. Then the stover is stacked. The harvested earheads are sundried before threshing. The grain is separated from the earheads by using a mechanical thresher or by moving a tractor or by drawing a stone roller over the ear-heads or by trampling under the feet of cattle.

## POST-HARVEST MANAGEMENT

After threshing, the sorghum grains are cleaned by winnowing and sundried before storage. Grain at or below 14% moisture is considered dry. For long-term storage (more than 6 months), grain moisture content should be a maximum of 13.5%. The storage structures in rural areas are not ideal from scientific storage point of view, as substantial losses occur during storage of grain from insect-pests, moulds, rodents, etc. Sorghum grain is stored traditionally in mud bins or straw bins or bamboo bins or in metal bins. Metal bins are better for safe storage of grain in rural areas. Sorghum grains are more prone to insect-pests attack during storage. The management strategy for stored pests has already been given in insect-pest management section in this chapter.

## USAGE

Sorghum is largely used as food and feed grain. Around 56% of sorghum grain is used for human consumption, 27% as poultry feed, 8% as animal feed, 7% for alcohol and 2% as seed and wastage (DSR, *Vision 2030*). *Kharif* sorghum grain is mostly used as feed for animals and poultry and raw material for alcohol distilleries. *Rabi* sorghum is a highly valued foodgrain. The pattern of utilization of sorghum grain for various purposes is given in Table 4.15.

## CROPPING SYSTEMS

Sorghum is an important component of cropping systems in rainfed areas. Being a widely row spaced (45 cm) and short- to medium-duration crop (90-120 days), sorghum provides opportunity for growing intercrops for better use of natural resources. The grain yield of sorghum has been found to increase by 34, 27, 20, 17, 12 and 8% owing to intercropping for cowpea (fodder), cowpea



**Table 4.15** Pattern of utilization of sorghum grain for various uses in India

Utilization pattern	Type	Demand (million tonnes)	
		Quantity utilized in 2008-09	Estimated utilization in 2011-12
A. Direct use/human consumption	a. Rabi	4.0	3.5
	b. Kharif	0.1	0.7
Sub-total (a+b)		4.1	4.2
B. Other uses			
1. Poultry feed	Kharif	2.0	3.18
2. Animal feed	Kharif	0.6	1.30
3. Alcohol	Kharif	0.49	2.50
4. Seed+waste	Kharif	0.15	0.20
Sub-total (1+2+3+4)		3.20	7.20
Total production		7.31	11.40

Source: Directorate of Sorghum Research, Hyderabad, *Vision 2030*

(grain), greengram, blackgram, groundnut and soybean, respectively, over sole sorghum under rainfed conditions (Singh, 1979).

#### Sorghum + pigeonpea intercropping

In assured rainfall areas and medium to heavy soils, an intercropping of sorghum with pigeonpea (2:1 or 2:2 or 3:2) or soybean (2:4 or 3:6) not only gives higher yields per unit area and time but also improves soil health and provides nutritional security to rural poor of the semi-arid tropics (Table 4.16). Sorghum+ pigeonpea intercropping at 2:1 or 2:2 row ratios was found to be promising (Rao *et al.*, 2003). The slow initial growth of pigeonpea does not provide any competition to sorghum crop for natural resources and being a leguminous crop, it helps in improving the soil fertility by fixing atmospheric nitrogen and heavy leaf fall. When the sorghum is harvested after 110-120 days,

**Table 4.16** Sorghum-equivalent yield and benefit : cost (B : C) ratio in sorghum + pigeonpea (PP) intercropping system as influenced by sorghum genotypes (mean of 4 locations: Coimbatore, Palem, Dharwad, Indore)

Cropping system	Sorghum-equivalent yield (tonnes/ha)	B:C ratio
CSH 16 + pigeonpea(PP) (2:1)	6.5	3.83
CSH 23 + PP (2:1)	5.9	3.35
CSV 15 + PP (2:1)	6.4	3.62
SPV 1616 + PP (2:1)	6.2	3.50
Local + PP (2:1)	6.4	3.47
CSH 16 sole	2.7	2.54
CSH 23 sole	2.4	2.26
CSV 15 sole	2.5	2.43
SPV 1616 sole	2.5	2.44
Local sole	2.5	2.53

pigeonpea grows vigorously utilizing the space left by the sorghum crop. Intercropping with sorghum also reduces the incidence of wilt disease in pigeonpea.

The sorghum genotypes vary in their growth behaviour, canopy development and duration. This may affect the growth and development of the pigeonpea crop grown in intercropping system. Intercropping of sorghum 'CSH 16' with pigeonpea (2:1) has been tested at different locations (Coimbatore, Palem, Dharwad and Indore) of the country and found beneficial over sole cropping. This system gave the highest sorghum-equivalent yield (6.5 tonnes/ha) and benefit : cost ratio (3.83), besides improving soil health and nutrition of people living in rural areas.

In a large part of sorghum area in Maharashtra and Madhya Pradesh pigeonpea has largely been replaced by soybean, because of higher monetary returns. The intercropping of sorghum with soybean could sustain sorghum production in these states. Results from Akola and Indore revealed that intercropping system is highly beneficial as compared to either of the sole cropping systems (Table 4.17). In Malwa region of Madhya Pradesh (Indore centre), sorghum genotypes JJ 1022, SPV 1616 and CSH 16 were found most compatible with soybean intercropping. However, sorghum genotypes differ in their compatibility with soybean (Table 4.18).

**Table 4.17** Grain yield of sorghum and soybean as influenced by row proportions (mean data of Akola and Indore locations over 3 years)

Treatment	Yield (tonnes/ha)			Monetary return (₹/ha)
	Sorghum	Soybean	Sorghum equivalent	
Sorghum+soybean (1:2)	2.27	1.02	5.34	22,120
Sorghum+soybean (2:1)	3.41	0.50	4.92	21,913
Sorghum+soybean (2:4)	2.08	0.90	4.79	20,154
Sorghum+soybean (3:3)	2.69	0.71	5.16	21,298
Sorghum+soybean (3:6)	1.96	0.91	4.69	19,805
Sole soybean	-	1.34	4.02	14,697
Sole sorghum	3.90	-	3.90	18,990
CD (P=0.05)			0.58	2,107

#### **Sorghum+ groundnut intercropping system**

Groundnut being a leguminous and low profile canopy crop, fits well with sorghum in intercropping system in semi-arid conditions. Results of the experiments conducted under AICSIP at Dharwad and Palem revealed that groundnut may be planted at 4:2 or 6:3 row ratios to get benefit of higher total productivity and gross returns (Table 4.19).

As the moisture is a limiting factor during post-rainy sorghum production, intercropping is feasible only in deep soils. Sorghum + chickpea and sorghum+ safflower are the important intercropping systems in *rabi* sorghum-growing regions of Maharashtra and Karnataka.



**Table 4.18** Sorghum-equivalent yield, net returns and benefit : cost (B : C) ratio in sorghum + soybean intercropping system as influenced by sorghum genotypes at AICSIP, Indore

Cropping system	Sorghum-equivalent yield (kg/ha)	Net returns (₹/ha)	B:C ratio
CSH 16 + soybean (2:4)	6,337	56,274	5.33
CSH 23 + soybean (2:4)	5,369	46,959	4.62
CSV 15 + soybean (2:4)	5,993	55,244	5.25
SPV 1616 + soybean (2:4)	6,374	59,681	5.60
JJ 1022 (Local) + soybean (2:4)	6,658	62,339	5.80
CSH 16 sole	3,305	29,472	3.02
CSH 23 sole	2,243	18,128	2.24
CSV 15 sole	3,498	33,651	3.31
SPV 1616 sole	3,382	34,172	3.34
Local (JJ 1022) sole	3,421	33,465	3.29
Sole soybean	6,835	49,152	5.12
CD (P=0.05)	682	5,156	0.85

**Table 4.19** Yield and gross monetary returns in sorghum + groundnut intercropping system at AICSIP, Dharwad

Treatment	Grain yield (tonnes/ha)		Sorghum-equivalent yield (tonnes/ha)	Gross monetary returns (₹/ha)
	Sorghum	Groundnut		
Groundnut + sorghum 2:1	3.6	1.7	8.9	31,057
Groundnut + sorghum 1:2	3.8	0.5	5.2	23,199
Groundnut + sorghum 4:2	4.7	1.7	9.9	35,579
Groundnut + sorghum 3:3	4.7	8.3	7.3	29,212
Groundnut + sorghum 6:3	3.2	1.3	7.4	27,263
Groundnut + sorghum 3:6	4.2	5.6	6.0	25,111
Sole sorghum	5.5	-	5.5	26,348
Sole groundnut	-	1.6	4.0	13,340
CD (P=0.05)	0.54	0.16	0.67	2,660

### VALUE-ADDITION

The decline in sorghum consumption may continue with the current structural transformation of our economy and globalization coupled with changes in life-style and food habits. Greater availability of fine cereals such as rice and wheat through public distribution system is another cause for lack of household demand. Development of sorghum for alternate uses and their popularization is highly essential for enhancing competitiveness of *kharif* sorghum. Further, sorghum though known as a nutritious grain, the consumption of this cereal is coming down due to the non-availability of, and easy methods



of cooking of fine cereals. There is a need to develop and popularize ready-to-cook or ready-to-eat sorghum foods for urban population as sorghum with its rich fibre and low starch digestibility makes an ideal food for diabetic and obese population. Development and empowerment of entrepreneurs especially belonging to women groups through value-addition will enhance the demand for sorghum. In this context, identification of suitable genotypes for specific end-products, suitable processing technologies and their respective machinery for semi-processed foods are essential. Different value-added products are being developed and popularized by the Directorate of Sorghum Research, Hyderabad.

### SWEET SORGHUM

Sweet sorghum was first introduced into the United States of America in 1852. With the increase in global fuel prices in the past few years and also the environmental pollution, there has been growing interest in supplementing fossil fuel supplies with biofuels (fuels that come from plants). By blending petrol (gasoline) with ethanol from sweet sorghum, developing countries can save on valuable foreign exchange spent on importing petrol and the environment. In India, the replacement of just 20% of the grain sorghum crop with sweet sorghum would meet the nation's target for ethanol for a 10% blend of ethanol in petrol. Sweet sorghum is the same species (*Sorghum bicolor*) as grain sorghum, but has high sugar content (10-15%) in the stalks. Although sweet sorghum is primarily grown to produce sorghum syrup, but being a water-use efficient crop, it has the potential to be a good alternative feedstock for ethanol production. It is a multi-purpose crop which can be cultivated for simultaneous production of grain from its earhead as food and feed ingredients, sugary juice from its stalk for making syrup, jaggery or ethanol, and bagasse and green foliage as an excellent fodder for animals, as organic fertilizer or for paper manufacturing.

In favourable environments, sweet sorghum varieties can grow 3 m tall and produce 50-125 tonnes of biomass (fresh weight)/ha. Like grain sorghum, it is also grown during rainy and post-rainy seasons. The productivity of sweet sorghum in post-rainy (*rabi*) (October-November planted) season is 30-35% less than that in rainy (*kharif*) and summer seasons because of short day-length and low night temperatures. In order to meet the industry demand for raw materials especially during lean periods of sugarcane crushing, there is a need to develop sweet sorghum cultivars that are photoperiod and thermo-insensitive with high stalk and sugar yields. The production technologies are similar to that of grain sorghum. A list of hybrids and varieties of sweet sorghum released and recommended for different regions is given in Table 4.20.

Influence of stage of harvesting on changes in stalk yield, quality, bioethanol yields and biomass indicated that fresh stalk yield increased from flowering to soft-dough stage and then declined until maturity. Harvesting at soft-dough stage gave maximum stalk yields, and CSH 22SS yielded the highest (39.0 tonnes/ha). There was 10% increase in bioethanol yields when sweet sorghum harvested at hard-dough stage than at physiological maturity (Table 4.21) and cv CSH 22SS recorded the highest bioethanol yield (AICSIP, 2006, 2007).



**Table 4.20** Plant characteristics, grain yield, stalk yield and juice quality of released hybrids and varieties of sweet sorghum

Cultivars	Year of release	Plant height (m)	Grain yield (tonnes/ha)	Stalk yield (tonnes/ha)	Ethanol yield (litres/ha)	Duration (days)	Juice (%)	Brix (%)	Adaptation (season)
CSH 22SS	2005	3.5	1.5-2.0	42-45	1,100	115-125	35-40	16-17	Irrigated areas of kharif season
<b>Hybrid (Irrigated)</b>									
<b>Varieties</b>									
SSV 84	1992	2.8	2.2-2.5	35-40	1,000	120-125	40-45	17-18	Suitable for kharif season
SSV 74	1999	3.6	2.0-2.1	40-42	1,100	125-130	40-45	17-18	Suitable for kharif season
CSV 19 SS	2004	3.6	0.8-1.0	40-45	1,000	115-120	32-36	16-17	Suitable for kharif season
PAC 52093	2005	3.6	1.5-2.0	40-45	1,000	115-120	35-36	16-17	Suitable for kharif season

**Table 4.21** Influence of stage of harvesting on calculated bioethanol yield in sweet sorghum

Cultivar	At 50% flowering stage	At soft-dough stage (15 DAF)	At hard-dough stage (30 DAF)	At physiological maturity	Cultivar mean
SSV 84	457	613	674	642	596
CSH 22SS	715	850	948	864	844
CSV 19SS	461	635	661	563	580
PAC 52093	554	835	872	816	769
Treatment mean	547	733	789	721	697
CD (P=0.05)					
Stage of harvest	215				
Cultivar	215				
Interaction	NS				
<i>Calculated bioethanol yield (litres/ha)</i>					

DAF, Days after flowering  
Source: AICSIP (2006, 2007)

### FORAGE SORGHUM

Sorghum for green forage is popularly grown over 2.6 million ha area in Western Uttar Pradesh, Punjab, Haryana, Delhi, Gujarat, Rajasthan and is fast becoming popular with farmers in other states. Almost 60-70% of total forage demand in *kharif* is met from sorghum. Multi-cut sorghum under irrigation in summer and single cut as rainfed crop in *kharif* are popular. Its quick growth, high-yielding ability, high dry-matter content, leafiness, wider adaptability and drought resistance make sorghum an ideal forage crop. Sorghum is suitable for silage and hay making and thus supplements the nutritious supply in lean season.

#### Crop improvement

Development of improved varieties/hybrids and production technology has led to an average yield of 50 tonnes/ha in single-cut forage sorghum and up to 70 tonnes/ha in multi-cut hybrids. A number of forage sorghum varieties have been released in our country. The list of single, multi-cut and dual-purpose sorghum genotypes is presented in Tables 4.22, 4.23 and 4.24 respectively.

**Table 4.22** Single-cut varieties of forage sorghum

Cultivars	Fodder yield (tonnes/ha)		Characteristics
	Green	Dry	
Pusa Chari 6	44	16.5	It flowers in 85-90 days. Stem is medium thick, non-sweet, pithy and non-juicy. Leaves are medium long and broad with white midrib. Panicle is semi-compact. Seeds are medium bold and white. It matures for seed in 135-140 days and gives 0.8-0.9 tonne/ha seed.
HC 136	55	17.5	It is tall, sweet, juicy and medium thick stemmed. The leaves are very broad and long with green midrib and remain green up to maturity. It has high protein, low toxic constituents and better digestibility. It is also good in regeneration and yields 80-85 tonnes green fodder and 26-28 tonnes dry matter/ha in two cuts. It matures for seed in 140 days.
Jawahar Chari 6 (JC 6)	41.2	12.0	Its stem is tall, thick, juicy and non-sweet. Leaves are broad and long with white midrib. It is tolerant to leaf-spot diseases. Panicle is semi-lax. It flowers in 80 days and matures in 130-135 days. Grains are bold, pearly white with reddish brown glumes.
UP Chari 1	33.0	9.0	It flowers in 75-80 days and thus becomes ready for fodder. Its stem is medium thick, sweet and

Table 4.22 *contd*



Table 4.22 concluded

Cultivars	Fodder yield (tonnes/ha)		Characteristics
	Green	Dry	
			juicy. Leaves are dark green, long and broad with green midrib. Panicle is medium in size, flat and chalky white. It matures in 115-120 days for seed and yields 0.8-1.0 tonne/ha seed.
UP Chari 2	38.0	12.5	It flowers in 75-80 days. It is medium thick stemmed with tan colour and juicy. Leaves are very broad and long having light green colour. Panicle oval-shaped, medium in size and compact. Grains are medium bold, round and pearly white in colour. It matures for seed in 110 days and gives 1.0-1.2 tonnes/ha seed yield.
Pusa Chari 9	42.5	13.5	It flowers in 80-85 days. It is medium thick stemmed, non-sweet and pithy. Leaves are long and medium broad with midrib. Panicles are semi-loose, straight but sometimes goose necked. It matures in 120 days and yields 0.8 tonne/ha.
Rajasthan Chari 1 (RC 1)	45.0	12.5	It flowers in 80-85 days. Its stem is medium thick, leaves long and dark green with white midrib. Earheads oblong fully exerted from the flag leaf. Grains are bold and chalky white. It matures for seed in 110-115 days.
Rajasthan Chari 2 (RC 2)	33.0	10.0	It flowers in 65-70 days. Its stem is medium thick, leaves light green having 60-70 cm length and 5-6 cm breadth with white midrib. Plants have 11-13 leaves with drooping habit. Earheads are fully exerted from the leaf. Grains are bold, flat and chalky white. It matures for seed in 100-150 days.
HC 171	41.0	12.2	Its stem is sweet and juicy and leaves have green midrib. Panicles are semi-compact with small and creamy white seeds. It is highly resistant to most of the foliar diseases being tan pigmented. It is highly resistant to mites.
HC 260	45.0	14.0	It becomes ready for fodder in 55-60 days and matures for seed in about 85-90 days. It is non-sweet and juicy. Leaves are medium broad and long with white midrib. Its panicles are semi-compact with white seeds. It is resistant to foliar diseases. It gives good seed.
Haryana Chari 6 (HC 308)	41.5	12.8	Tall, leafy and medium maturity, stem is sweet and juicy, highly resistant to all foliar diseases, midrib green, panicle semi compact.

Table 4.23 Multi-cut cultivars of forage sorghum

Variety/ hybrid	Fodder yield (tonnes/ha)		Characteristics
	Green	Dry	
MP Chari (Variety)	30.0	9.5	Tall, thin stemmed, leaves medium long and narrow with white midrib. Non-sweet, non-tan, non-juicy and pithy. Takes 65-70 days to become ready for fodder. Panicles are erect and lax with purple or black glumes. Grains brown coloured. Better generation and for two cuttings. Crop matures for seed in about 110 days. Leaf-spot disease susceptible.
Meethi Sudan SSG 59-3	57.0	13.8	A popular multicut sudan grass. This variety is suitable for 4 cuts for green fodder during the crop season. It is thin stemmed, sweet with profuse tillering, early flower in 55-60 days. Tolerant to drought and waterlogging. Panicle is lax with profuse lateral spikes. Seeds purple red with glumes adhered to them. Matures in 95-100 days and yields 1.0-1.2 tonnes/ha seed.
Jawahar Chari 69 (JC 69)	50.0	16.5	A multicut sudan type having high regeneration and faster growth and multicut ability. Its stem is thin and non-sweet and leaves are narrow and long with white midrib. Its panicle is highly lax with small seeds covered with black or brown glumes.
Pusa Chari 23	55.0	16.0	A multi-cut variety with thin stem, sudan type non-sweet and non-juicy. Leaves narrow with white midrib. Plants have lateral branches. Seed yield 1.4 tonnes/ha under North Indian conditions.
Hara Sona (Hybrid)	63.0	14.7	Multicut forage hybrid, 3 cuts, 5-6 tillers, days to flower 60-65, 9-10 leaves, quick in regeneration, thin stem, non-juicy, non-tan and palatable. It is recommended for Punjab state.
Punjab Sudex (Hybrid)	59.2	17.0	Multicut hybrid 3-4 cuts, 8-10 tillers under irrigation, takes 60-64 days for flowering, 10 leaves, profuse tillering habit, quick regeneration, thin stem, non-juicy, non-tan and palatable. It is recommended for Punjab state.
PCH 106 (Hybrid)	64.0	18.0	Multicut forage hybrid (Pedigree 2219 A × PC 23), suitable for 3-4 cuts, profuse tillering, quick regeneration, thin stem, non-tan, flowers in 60-63 days. Recommended for all sorghum-growing areas in the country.
CSH 20MF	74.2	19.8	Tan, dark green heavy foliage with green midrib. Medium thick juicy stem, resistant to foliar diseases. For all India cultivation.
CSH 24MF	91.3	23.2	Plant height 200-210 cm with tan pigmentation, light green foliage with brown midrib, semi-drooping, thick and juicy stem, narrow cylindrical semi-compact panicle with straight peduncle, white, medium bold seed, for all India cultivation.



**Table 4.24** Dual-purpose sorghum cultivars for forage production

Variety/ hybrid	Fodder yield (tonnes/ha)		Characteristics
	Green	Dry	
CSV 15 (as fodder variety)	44.0	12.8	It is a dual-purpose variety but can be grown as single-cut forage variety in North-Western India. It is tall, juicy with sweet stem, flowering in 68-70 days, tan, stay green, resistant to leaf spot diseases. Tolerant to grain mold and drought. Its seed can be multiplied in Bundelkhand and Northern Madhya Pradesh as a dual-purpose variety and sold for fodder purpose.
CSH 13 (as fodder hybrid)	48.0	14.5	Green forage yield as single cut, 10% higher than HC 6. Tan, resistant to leaf spot diseases, juicy stem, early vigour, stay green as multi-cut, gives more yield in first cut, flowering in 68-70 days.

**Production technology**

The suitable cultural practices for forage production are:

*Field preparation:* In general, 2-3 harrowings followed by planting is sufficient for sowing of forage sorghum. In unirrigated areas, sorghum for fodder should be sown immediately after the onset of monsoon.

*Sowing time:* The single-cut and two-cut varieties may be planted between 15 June and 30 June, with the onset of monsoon. In *tarai* (foot-hill) region of Uttar Pradesh, the best time of sowing is from the last week of May to the first fortnight of June. This helps in avoidance of major pests. The multi-cut varieties/hybrids can be planted early under irrigation as a summer crop.

*Seed rate and method of sowing:* Depending on seed size 25 kg seed/ha in small-seeded varieties and 40 kg/ha in bold-seeded varieties is recommended. The row-to-row spacing of 30 cm is optimum for higher fodder yield and better quality.

*Nutrient management:* Sorghum being a cereal and high biomass crop requires balanced fertilizer application to get high yields. In case of single-cut varieties 80 kg N/ha in two split doses is optimum under irrigated condition; first half as basal at last ploughing or at sowing and the remaining half 35-40 days after sowing. In rainfed areas, 40 kg N/ha (all basal) is recommended.

In multi-cut varieties, 100-120 kg N/ha is recommended in three split doses; first one-third dose at sowing, the second one-third dose after first cut and the remaining dose after the second cut.

*Irrigation:* In summer season the crop should be irrigated 3-4 times at the interval of 10-15 days to get better fodder yields. During *kharif* season, irrigation is adjusted according to rainfall distribution and 1-2 irrigations may be given during long dry spells.

*Weed control:* Weeds are a major problem in initial stage of crop growth and compete for water and nutrients. Summer ploughing to keep field weed free, 1-2 hand-weedings 15-20 days after crop sowing reduce weeds considerably.



Per-emergence spray of atrazine @ 0.5 kg a.i./ha effectively controls the weeds. Spray of weedicide should be taken immediately after sorghum sowing.

**Mixed cropping:** The planting of fodder legumes like cowpea and *guar* along with sorghum in 2:1 ratio increases fodder yield and quality. In low rainfall or less irrigated areas mixed cropping of sorghum and *guar* is desirable. In irrigated or high rainfall areas, mixed cropping with cowpea gives high fodder yield. The erect variety of fodder cowpea is preferred.

**Crop rotation:** The yield of sorghum is high when planted after taking the leguminous crop like berseem, *senji* and *metha*. It saves nitrogen application to sorghum crop. The crop rotations fodder sorghum-wheat; fodder sorghum-chickpea or pea are popular. Thus, early flowering variety or early planting is useful to get higher yields of forage sorghum as well as *rabi* crop.

### Harvesting

**Single-cut:** Such varieties are harvested from 50% flowering to full flowering.

**Multi-cut:** In multi-cut varieties first cut taken 55 days after sowing gives higher green fodder yield, whereas dry-matter production is more when crop is harvested at 70 days after sowing. Subsequent cut at 40 days interval is invariably found to be the best as it gave the highest green as well as dry-matter production.

### Management of HCN poisoning

HCN is maximum at 35-40 days stage of crop growth. It decreases gradually with the growth of the crop. The HCN in excess of 200 ppm is toxic. HCN content increases under moisture stress. In most of sorghum varieties, HCN decreases below toxic level after 40 days of the crop growth. In summer, crop should be irrigated 2-3 days before harvesting or else it is safer to harvest crop after flowering.

### Insect-pest control

Same as for grain sorghum. However, since green fodder is fed to cattle, insecticide application should be avoided.

### Seed production

Maximum seed yield of single-cut forage types is obtained when 25 kg seed/ha is used with 45 cm row spacing and 10-15 cm spacing between plant to plant. However, in dual-purpose variety, the seed rate 8-10 kg/ha is optimum.

### SUMMARY

- Sorghum is a rainfed staple cereal grown in the semi-arid and arid parts of India. Apart from serving as staple cereal for the poor in India, it is also an important source of fodder for animals. With the increase in human and animal population and a fragile balance between food supplies and its demand, production of sorghum must be increased to meet the current and future fodder for domestic animals.



- Globally, sorghum is cultivated in 40 million ha area, producing about 56 million tonnes grain with an average yield of 1,404 kg/ha. India and Africa account for the largest share (>70%) of global sorghum area. In India, sorghum is cultivated during both rainy (*kharif*) and post-rainy (*rabi*) seasons, mainly as a rainfed crop. Maharashtra is the largest sorghum grower and producer followed by Karnataka, Madhya Pradesh and Andhra Pradesh.
- Sorghum belongs to the tribe Andropogoneae of family Poaceae and sub-family Panicoideae. Based on mature spikelet types, cultivated sorghum (*Sorghum bicolor*) has been classified into five basic races, viz. *Bicolor*, *Guinea*, *Caudatum*, *Kafir* and *Durra*. The first commercial sorghum hybrid 'CSH 1' was released in 1964 and since then 25 hybrids and 25 varieties of different types of sorghum (grain, dual-purpose, sweet and forage) have been released so far for commercial cultivation throughout India, besides there are a number of varieties released for specific regions by the respective state SAUs and research organizations. Hybrids and dual-purpose varieties are most common during *kharif* season, while in *rabi*, dual-purpose varieties are widely adopted. For *rabi* season, varieties have been released specific to soil types, viz. shallow, medium and deep.
- *Kharif* sorghum is sown with the onset of monsoon over a period of two weeks (normally first fortnight of July), while optimum sowing time for *rabi* sorghum varies from third week of September to first week of October. Crop is sown in rows 45 cm × 15 cm apart at 4-6 cm seeding depth with seed rate 8-10 kg/ha. Optimum plant density is 1.8 lakh in *kharif* and 1.35 lakh in *rabi*/ha. First thinning should be done 10-15 days after emergence and second, when the crop is 25-30 days old. Sorghum has three distinct phases, viz. vegetative, floral initiation and grain-filling, in its life-cycle. Half amount of N (40 kg) and full dose of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O is applied basal at sowing. Remaining half N (40 kg) is top-dressed 30-35 days after sowing. Integrated nutrient management by applying 75% recommended dose of fertilizer (RDF) + farmyard manure (FYM) + biofertilizer [*Azospirillum* and phosphate-solubilizing bacteria (PSB)] has been found on a par with application of 100% RDF. Mid-season drought in *kharif* sorghum and post-flowering drought in *rabi* sorghum are the major constraint across the production zones in India. *In-situ* moisture-conservation practices, viz. tied ridges and compartment bunding have been found beneficial in conserving higher soil moisture for *rabi* sorghum. In case of limited water availability, crop is irrigated at the flower primordial initiation stage (30-35 days after sowing) followed by flowering stage.
- Due to wider row spacing and slow initial growth rate, sorghum is heavily infested with weeds, especially during the rainy season resulting in 15-65% loss in productivity. Weeds in sorghum can be managed mechanically by hand tools or inter-row cultivators between 3 and 6 weeks after sowing. Cultural practices such as crop rotation, intercropping with groundnut, soybean and cowpea and green-manuring crops like sunn hemp help in reducing weed problem including parasitic weed *Striga*. Combination of



pre-emergence herbicides, viz. atrazine, metolachlor or pendimethalin and intercultural operations (hoeing and hand-weeding at 30-35 days after sowing) has been found effective and economical.

- Sorghum + pigeonpea intercropping system is widely practiced during *kharif* with high degree of stability and higher productivity in semi-arid regions. Soybean, groundnut, greengram, blackgram and cowpea are the other crops grown as intercrop with *kharif* sorghum. Safflower and chickpea are also grown as intercrop with *rabi* sorghum in some areas.
- Pests like shoot fly, stem-borer and head bug cause damage to the crop. Diseases like grain mold, followed by ergot are the major yield reducers. Integrated management approach with emphasis on host plant resistance and cultural methods is being pursued vigorously to control these pests and diseases. In addition, a number of insect-pests such as rice weevil grain moth etc. cause considerable losses in storage. The best stage to harvest sorghum is when the plants reach the physiological maturity.
- Sorghum is largely used as food and feed grain. Around 56% of sorghum grain is used for human consumption, 27% as poultry feed, 8% as animal feed, 7% for alcohol and 2% as seed and wastage. Although sorghum is a nutritious grain, the consumption of this cereal is decreasing due to the easy availability of rice and wheat. There is a need to develop and popularize ready-to-cook or ready-to-eat sorghum foods for urban population (less time consuming) as sorghum with its rich fibre and low starch digestibility makes an ideal food for diabetic and obese population.
- Use of sorghum as animal fodder is equally important in semi-arid regions and peri-urban areas. A large number of hybrids and varieties of single and multi-cut sorghum have been developed by the public and private sectors.
- With the increase in global fuel prices in the past few years and also the environmental pollution, there has been growing interest in supplementing fossil fuel supplies with biofuels and sweet sorghum is emerging as a potential feedstock for biofuels.

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## Pearlmillet

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Pearlmillet [*Pennisetum glaucum* (L.) R. Br. emend. Stuntz], also known as candle millet, cattail millet, bulrush millet or *bajra*, is an important crop of rainfed areas of Africa and India and serves as staple food for West African people. India is the largest producer of pearlmillet covering about 8.75 million ha of marginal and sub-marginal lands primarily in the states of Rajasthan, Gujarat, Haryana, Uttar Pradesh and Maharashtra and is the fifth important cereal after rice, wheat, maize and sorghum. In addition to its grain consumption as human feed, it is also used as green fodder in India, Pakistan, Russia, Australia and the USA.

Pearlmillet provides staple food for the poor in a short period in relatively dry tracts of the country and is cultivated by the economically poor farmers using little or no improved production technology. From quality point of view pearlmillet grain is more nutritious than other cereal grains; and is rich in minerals (2.0-3.5%) and fat (4.0-8.0%). Pearlmillet grains possess high protein content (10.5 to 14.5%) with higher levels of essential amino acids. Nevertheless, the grain of pearlmillet is deficient in lysine content, like other cereals. The popular hybrid and composites of pearlmillet on an average contain 11.6% protein, which is higher than the protein content of sorghum and maize. It also contains a fairly high amount of carotene, riboflavin and niacin. The grains of pearlmillet possess a biological value similar to wheat and rice and impart substantial energy to the body. The energy level of 361 k cal is the highest among the grain cereals.

Based on the bulk of evidence in genetic variability and morphological diversity, it is believed that primary centre of origin of pearlmillet is Africa from where it spread to India and other countries. Out of 32 species described by Stapf (1934), only two are known outside the African continent. They are *Pennisetum glaucum* (pearlmillet) and *Pennisetum perpureum* (elephant grass) and both have a common ancestor. A great range of genetic variability is found in the strains from Africa. Once domesticated it spread through the drought plagued regions of the Sahara and Sahel region of Africa and its area expanded proportionately to the expansion of desert.

### DISTRIBUTION AND SPREAD

Pearlmillet is a warm weather coarse cereal grown in semi-arid and arid climate of tropical and subtropical regions, as it is endowed with greater ability to withstand harsh environment. Pearlmillet plant does not resist the drought but cuts short its life cycle and comes to flowering early under such adverse conditions. Because of this drought-escaping mechanism pearlmillet can grow in areas that have extended dry periods. It can be grown successfully with rainfall varying from 50 to 1,300 mm but grows well in regions receiving average annual rainfall around 500 mm. Globally, pearlmillet is grown in an area of 31.9 million ha (Mha) with a total production around 28 million tonnes (Mt) and average productivity of 890 kg/ha. It is cultivated mostly between 15°W and 90°E longitude and 5°S and 40°N latitude. Cultivation of this crop is confined to drier tracts of Asia (mainly India, China and Pakistan) and Africa (Nigeria, Niger, Sudan, Mali, Chad, Tanzania and Senegal) (Table 5.1).

**Table 5.1** Area, production and productivity of pearlmillet in important countries of the world during 2010

Country	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
India	8.50	8.59	1,010
Nigeria	5.85	7.70	1,320
Niger	5.20	2.68	520
Sudan	2.25	0.47	210
China	0.90	1.60	1,780
Total world	31.92	28.32	890

Source: USDA (2012)

In India, pearlmillet is grown in 8.75 million ha of cultivated land distributed in most of the states except those having high rainfall. Out of the total area under pearlmillet, nearly 87% lies in the states of Rajasthan, Maharashtra, Gujarat, Western Uttar Pradesh and Haryana. Over 94% of the pearlmillet areas in the country are rainfed. Area, production and productivity of this crop in these states are given in Table 5.2. During the period 1961 and

**Table 5.2** Area, production, productivity of pearlmillet in important states of India

State	Area (million ha)		Production (million tonnes)		Productivity (kg/ha)	
	1961	2009	1961	2009	1961	2009
Rajasthan	4.20	5.17	1.04	4.28	247	828
Maharashtra	1.67	0.87	1.04	0.66	258	765
Gujarat	1.21	0.70	0.48	0.96	394	1,365
Uttar Pradesh	0.95	0.81	0.38	1.30	426	1,609
Haryana	0.50	0.61	0.29	1.08	298	1,769
All India	-	8.75	-	8.89	-	1,015

Source: FAI (2011)



2009 the area under pearl millet increased by 23% in Rajasthan and by 22% in Haryana, but it decreased in other states; however the production increased in all the states except Maharashtra, mainly owing to increase in productivity because of development of high-yielding varieties and hybrids and improved agronomic management practices.

India has been divided into four ecological zones for pearl millet cultivation.

*Ecological Zone I:* Adequate to abundant rainfall and light soils (Punjab, Uttar Pradesh, Delhi, Haryana and adjacent Madhya Pradesh).

*Ecological Zone II:* Limited rains but heavy to loamy soils (Gujarat, Maharashtra and Madhya Pradesh).

*Ecological Zone III:* Low rainfall and light sandy and sandy-loam soils (Rajasthan, Karnataka and North-Central Andhra Pradesh).

*Ecological Zone IV:* Limited but well distributed rainfall (Tamil Nadu, Coastal Andhra Pradesh).

### TAXONOMY

The pearl millet belongs to the family Gramineae (Poaceae). The diploid chromosome number is  $2n=14$ . The genus *Pennisetum* is divided by Stapf into five sections: (a) Gymnothria, (b) Eupennisetum, (c) Pennicillaria, (d) Heterostachya and (e) Brevivalvula. The cultivated species *P. glaucum* belongs to the section Pennicillaria distinguished from the others by the conspicuous pennicillate anthers. Stapf included thirty-two species in Pennicillaria. Out of the thirty two species found in Africa six annuals are considered wild and probable ancestors of the cultivated *P. glaucum*. These are *P. perrottettii*, *P. mollissimum*, *P. violaceum*, *P. versicolor*, *P. adoense* and *P. gymnothrix*. The cultivated species is believed to have originated through hybridization within these six species.

The other species in this section is *P. purpureum* Schum. (napier grass) ( $2n=28$ ) —a rhizomatous perennial which is cultivated for forage. It crosses readily with the cultivated diploid producing sterile allotriploid hybrids ( $2n=21$ ). The hybrid resembles mostly *P. purpureum*. On the basis of these cytological evidence, *P. purpureum* is considered to be an allotetraploid with one of its genomes similar to that of *P. glaucum*. This species is supposed to be an introduction from Africa. This has been used in interspecific hybridization with *P. glaucum* for transferring specific characters like rust resistance and also for having vigorous types for forage as in the case of Pusa Giant Napier.

### MORPHOLOGY

Pearl millet is a tall, warm weather, short-day annual plant. Its height ranges from 1 to 3 m. The stem is solid, rounded to oval in cross-section. The nodes are slightly swollen; softy villous, while internodes are cylindrical and glabrous. The internodal length increases from the base of the culm upwards. A shallow groove is found just above each node. The axillary bud is placed in this groove. The node is slightly swollen and bears the ring of adventitious root primordia at the basal end. The leaves are linear, usually scabrous or with sparse hairs or very hairy or glabrous; the base of the blade is slightly auricled; the ligule is



narrow membranous with a fringe of hairs; it closely surrounds the stem; a thin translucent portion called leaf junction connects the lamina with the sheath; the leaf sheath completely encircles the stem; it is thicker than the lamina.

The inflorescence is terminal. The appearance of the flag leaf or boot leaf marks the end of the vegetative phase, and the stem stops further elongation. The panicle gradually pushes its way upwards and out of this sheath, until the entire panicle is free. The peduncle is thin, cylindrical, clothed with soft, more or less woolly hair below the base of the region of the spikelet. The rachis is straight, cylindrical, solid, covered with soft villous, short hair. Rachillae bearing clusters of spikelet are arranged spirally on the rachis; rachillae are small and covered with short hair and are shortest at the apex of the panicle and arranged densest at about the middle portion. The spikelets are small, lanceolate in shape and sharply acute. Each spikelet consists of two sterile glumes and two florets, the lower floret being usually male and the upper hermaphrodite. There are three stamens with characteristic pennicillate anthers. The ovary with a single style is bifid at the tip into two non-plumose stigmas. The gynoecium is protogynous, and the grains, a caryopsis, are grey, rarely yellow.

#### **Anthesis and pollination**

Cross pollination is the rule in pearlmillet. On emergence of the inflorescence, the bluish-white styles protrude. The styles emerge when the spikelets are mature, irrespective of whether the panicle is still inside the boot or partially or fully emerged, so much so, that often panicles which are fully enclosed in the boot will have fully exerted stigmas. The time taken for the emergence of the stigma varies from 12 to 24 hours depending on the season. The two stigmas separate out and diverge only after full exertion of the style. The protogynous condition is helpful in the emergence of the anthers from the hermaphrodite flowers. The second wave from staminate flowers begins about two to three days after the first style has emerged. The largest number of anthers emerges between 8 PM and 2 AM with the peak at about 10 PM. The emergence of anthers is uninterrupted continuing during both day and night. It has been noted that an increase in humidity and lowering of temperature induces anthesis. Pearlmillet is sensitive to photoperiod. Long photoperiods over 14 hr can double the grain yield as compared to 12 hr photoperiod.

#### **Grain**

In about seven to eight days from the first appearance of the inflorescence, the development of the ovaries commences. By the end of the first week of its growth the ovary grows so much as to become visible outside the glumes. In the initial stages the ovary is succulent and it slowly turns soft and milky. In another week, the grain is fully developed and in the following week it hardens gradually. The grain is a caryopsis, almost oval in appearance with one of its ends tapering and it is at this tapering end that it is attached to the spike. The colour of the grain varies from whitish yellow to dull light blue. The outer surface is smooth and shining. The embryo is small and pressed to one side at the tapering end of the grain.



### GROWTH STAGES

The grains absorb moisture to about 50% of their weight and swell up. The coleorhiza is the first to appear outside the pericarp and this takes place after a day of soaking, i.e. roughly after 24 hr. In another 12 hr, the primary root emerges out of the coleorhiza and at about the same time the coleoptile of the plumule breaks through the pericarp. The first leaf emerges from the splitting of the coleoptile only after the coleoptile comes out of the soil.

The primary root grows downwards and produces lateral roots which are very thin and delicate. As the hypocotyl region is pushed out of the grain and the lower nodes of the leaves are produced, adventitious roots arise from these nodes. The roots penetrate about 60 cm into the soil. The roots arising from the tillers show a greater horizontal spread than a deeper penetration. The lateral roots are thinner and fibrous while the main roots become more woody.

Ontogeny of pearl millet is characterized by sequential completion of the following developmental stages (Gregory and Squire, 1978) in order the following.

1, germination of seed; 2, seedling emergence; 3, seedling establishment; 4, tillering; 5, final leaf stage; 6, booting; 7, panicle emergence; 8, half bloom stage; 9, fertilization; 10, seed set; 11, milking; 12, soft dough stage; 13, hard dough stage; 14, physiological maturity.

Many of the above growth stages cannot be clearly demarcated and usually these overlap. Therefore, Maiti and Bidinger (1981) differentiated three major growth stages.

#### Growth stage 1

It is vegetative phase including seedling emergence and plant growth up to panicle emergence. Rapid growth allows better establishment of plants. Around 6-7 leaves are initiated during this stage. Growth stage 1 ends with panicle emergence. Depending on the environment and varietal characters this stage lasts for 50-80 days.

#### Growth stage 2

It is the panicle-development stage. During this stage stem elongation, complete expansion of the leaves and earhead formation takes place. Tillers developed after this stage may not complete all growth stages.

#### Growth stage 3

Grain-filling stage begins with fertilization of flowers followed by increase in grain weight. The stage ends with onset of senescence, all barring 3 or 4 leaves are retained till the end. Development of dark layered tissue in hilar region of seed indicates physiological maturity.

### VARIETAL DEVELOPEMENT

A complete list of pearl millet hybrids is given in Table 5.3, and of open-pollinated varieties in Table 5.4.

**Table 5.3** Pearlmillet hybrids released in India since 1965

Hybrid	Developed at place or organization	Year of release	Parentage
HB 1	Ludhiana	1965	Tift 23A x Bil 3B
HB 2	Jamnagar	1966	Tift 23A x J 88
HB 3	Jamnagar	1968	Tift 23A x J 104
HB 4	Kanpur	1968	Tift 23A x K 560
HB 5	Kanpur	1969	Tift 23A x K 559
NHB 3	Delhi	1975	5071A x J 104
NHB 4	Delhi	1975	5071A x K 560-230
NHB 5	Delhi	1975	5071A x K 559
PHB 10 (HB 6)	Ludhiana	1975	Pb 111A x PBH 155
PHB 14 (HB 7)	Ludhiana	1975	Pb 111A x PIB 228
GHB 1399	Jamnagar	1975	1226D2A x J 1339
BJ 104	Delhi	1977	5141A x J 104
CJ 104	Delhi	1977	5054A x J 104
BK 560	Delhi	1977	5141A x K 560-230
BD 111	Delhi	1977	5141A x D 111
COH 12	Coimbatore	1980	5141A x PT 1921
CM 46	Delhi	1981	5054A x M 46
GHB 27 (MH 28)	Jamnagar	1981	5141A x J 2002
BD 763	Delhi	1982	5141A x D 763
MBH 110	MAHYCO, Jalna	1982	MS 2 x PL 2
GBH 32 (MH 29)	Jamnagar	1983	5141A x J 1188
PHB 47	Ludhiana	1983	Pb 111A x PHB 1234
X 5	Coimbatore	1984	Pb 111A x PT 1921
HHB 45	Hisar	1984	5141 x H 90/4-5
MBH 118	MAHYCO, Jalna	1986	MS 2 x PL 3
MH 179 (ICMH 451)	ICRISAT	1986	81A x ICMP 451
MH 180	ICRISAT	1986	834A x ICMP 501
MH 182	Pune, Coimbatore	1986	732A x PNB 83099
HHB 50	Hisar	1986	81A x H 90/4-5
BGH 50	Jamnagar	1987	5054A x J 2022
MH 143	ICRISAT	1987	841A x ICP 423
PUSA 23	Delhi	1988	841A x K 560-230-23
MH 312	ICRISAT	1988	81A x BSEC TCP 2
HHB 60	Hisar	1989	81A x 833-2
MBH 136(MH 123)	MAHYCO, Jalna	1989	MS 2 x PL 6
MBH 149 (MH 249)	MAHYCO, Jalna	1989	MS 4 x PL 13
HHB 67	Hisar	1990	843A x H 77/833-2
VBH 67	Vijayaseeds	1990	VBMS 1A x VBR 19
MLBH 104	Mahendra	1991	MS 53A x 13
Eknad 301	Nathseeds	1991	NBMS 13A x NB 37
HHB 68	Hisar	1993	842A x H 77/833-2
ICMH 356	ICRISAT	1993	ICMA 88004 x ICMR 87003

Table 5.3 contd



Table 5.3 *concluded*

Hybrid	Developed at place or organization	Year of release	Parentage
Pusa 322	Delhi	1993	841A x PPMI 301
X 6	Coimbatore	1993	732A x PT 3095
RHRBH 8609	Rahuri	1994	RHRBH 1A x RBRBI 138
AHB 251	Aurangabad	1994	81A x AIB 16
GHB 15	Jamnagar	1994	5054A x J 108
GHB 235	Jamnagar	1994	81A x J 2296
RHB 58	Jaipur	1995	81A x RIB 20 K 86
Pusa 444	Delhi	1995	189A x PPMI 301
MLBH 267	Mahendra	1996	MS 3A x MI 53
MLBH 285	Mahendra	1996	MSIIA x MI 51
Nandi 30	New Nandi	1996	NMS 3A x NMP 13
RHB 30	Jaipur	1997	843A x RIB 335/74
GHB 183	Jamnagar	1997	81A x J 998
X 7	Coimbatore	1997	L 111A x PT 1890
BHRBH 8294 (Sabouri)	Rahuri	1997	RHRB 5A x RHRB 458
Pusa 415	Delhi	1999	576A x PPMI 301
Pusa 605	Delhi	1999	841A x PPMI 69
RHB 90	Jaipur	2000	81A x RIB 3135-18
HHB 94	Hisar	2000	ICMA 89111 x G 73-107
RHB 121	Jaipur	2001	ICMA 89111 x RIB 3135-18
GHB 526	Jamnagar	2003	ICMA 95222 x J 2372
GHB 558	Jamnagar	2003	ICMA 94555 x J 2290
HHB 146	Hisar and ICRISAT	2003	ICMA 95222 x HTP 94/54
HHB 117	Hisar	2004	HMS 7A x H 77/29-2
GHB 577	Jamnagar	2004	JMS A 101 x J 2405
HHB 67 Improved	Hisar	2005	ICMA 843-22 x H 77/833-2-202
GHB 538	Jamnagar	2005	ICMA 95444 x J 2340
GHB 719	Jamnagar	2007	ICMA 95222 x J 2454
GHB 732	Jamnagar	2008	ICMA 96222 x J 2340
HHB 197	Hisar	2008	ICMA 97111 x HBL 11
PHB 2168	Ludhiana	2008	ICMA 92333 x PIB 686
PB 727 (Proagro 9555)	Bayer, Hyderabad	2008	PSP 51 x PP 38
JKBH 676	JK Agrigenetics	2009	JKMS 20 A x JKR 6136
RHB 154	Jaipur	2009	ICMA 95444 x RIB 57 S/05
Nandi 64	New Nandi	2010	NMS 2-11A x NMP 4-1
HHB 216	Hisar	2010	HMS 37A x HTP 3/13
HHB 223	Hisar	2010	ICMA 94555 x HPL 11
Nandi 61	New Nandi	2010	NMS 24 A x NMP 64
Nandi 65	New Nandi	2010	NMS 24 A x NMP 75
RHRBH 9808	Dhule	2010	RHRB 13 A x RHRBI 1314

Source: AICPMIP (2012)

**Table 5.4** Open-pollinated varieties of pearlmillet released in India

Variety	Developed at place or organization	Year of release
ES 1	Hisar	1978
PSB 8	Ludhiana	1982
WC 375	ICRISAT	1982
Co 6	Coimbatore	1983
RCB 2	Jaipur	1985
HC 4	Hisar	1985
ICMS 7703	ICRISAT	1985
Co 7	Coimbatore	1986
Sangam (RHR 1)	Rahuri	1986
PCB 15	Ludhiana	1986
ICTP 8203	ICRISAT	1988
Pusa Safed	Delhi	1989
ICMV 155	ICRISAT	1991
Raj 171	Jaipur	1992
ICMV 221	ICRISAT	1993
Pusa 266	Delhi	1996
CZ-IC 923	Jodhpur	1996
Anantas	Anantpur	1997
CZP 1C 923	Jodhpur	1997
Pusa Composite 334	Delhi	1999
HC 10	Hisar	2000
Pusa Composite 383	Delhi	2001
HC 20	Hisar	2002
CZP 9802	Jodhpur	2003
Parbhani Sampada	Aurangabad	2005
JBV 4 (MP 403)	Gwalior	2007
PCB 164	Ludhiana	2007
Pusa Composite 443	Delhi	2009

Source: AICPMIP (2012)

Some identified hybrids are Pusa 23 (MH 169), Pusa 322, ICMH 451 (MH 179), ICMH 356, HHB 60, HHB 67, HHB 68, HHB 50, RHB 30, RHB 90, MH 605 (Pusa 605), MH 790, MH 782.

In addition to hybrids and open-pollinated varieties, some composites have also been developed. Some pearlmillet composites are: Pusa Composite 443, Pusa Composite 383, ICTP 8203, HB 4, WCC 75, ICMV 221, ICMV 155, Raj 171, HP 8601, Pusa Bajri 266, MP 334.

### CLIMATE

Pearlmillet grows better in warm dry climate with adequate soil moisture. It is a rainfed crop and is mostly grown in the areas where the average rainfall is between 400 mm and 750 mm during the entire growing period. It can withstand soil-moisture stress up to a great extent and even the sandy soils of



western Rajasthan where average annual precipitation is 150-200 mm are capable of producing a good crop with moisture-conservation practices. Light and a well-distributed monsoon season with few cloudy days is sufficient for ideal growth and development. During the vegetative growth of the crop, moist weather and light to medium rainfall is useful, while during flowering and grain formation there should be no rain and the weather should be clear and dry. Grain formation is adversely affected and results in poor grain setting if rains continue till that stage. If there is rain at the grain-maturity period, the grains get infected with diseases like ergot, which appear due to high humidity.

Waterlogged conditions are not congenial for this plant to grow; therefore, this crop should not be grown in low-lying areas. Pearlmillet has the potential to germinate over wide range of temperature from 15° to 40°C. However, a temperature of 28-32°C is considered to be optimum for the vegetative growth of the crop. High temperature at this stage induces early flowering and low temperature increases the chances of ergot infection. It is, therefore, recommended to follow optimum sowing time to protect this crop from the incidence of diseases. Pearlmillet has high rate of photosynthesis, the maximum rate observed was 277 mg/cm<sup>2</sup>/S (Mc Pherson and Slatyer, 1973). A temperature of 35° to 40°C is found to be optimum for the highest net photosynthesis.

### SOILS

Pearlmillet is successfully grown on a wide range of soils ranging from Aridisols (sandy soils) in Rajasthan to Vertisols (black cotton soils) and Ultisols (red and laterite soils) of central and peninsular India. Heavy soils are, however, not suitable for pearlmillet cultivation. Loamy sands to loams which are well drained and free from salinity and alkalinity are ideal for pearlmillet. Pearlmillet can give fairly good yield on alkaline soils but not on highly saline soils. The crop performs fairly well on poor soils where other crops cannot be grown successfully.

### TILLAGE AND SEEDING

#### Land preparation

Being small-seeded crop pearlmillet requires a fine and smooth seedbed which is free from clods. Nearly 2-3 ploughings are given to prepare a fine seedbed. In moisture-deficit areas, the tillage operations before and after seeding the crop are extremely important as they are associated with the conservation of rainwater. In such cases summer ploughing every year and deep ploughing once in 3-4 years are recommended. The deep ploughing is also advantageous for perennial weed control, release of nutrients from subsoil and retention of moisture (Malik *et al.*, 1973). To minimize damage due to termites, application of furadon @ 5-8 kg/ha is recommended. The water-holding capacity of both the coarse-textured desert soils in western India and the red sandy-loam soils of southern India is extremely low. Subramaniam *et al.* (1973) reported that organic materials like rice-husk or farmyard manure (FYM) @ 25 tonnes/ha if incorporated to a depth of 20-45 cm, 8 weeks before sowing improved the water-holding capacity of soil and increased the grain yield. A flat seedbed



stores more moisture, gives significantly higher grain yield and also increases the uptake of NPK compared with ridge and furrow beds (Ali and Prasad, 1974).

### Sowing

*Time of sowing:* It is an established fact that optimum time of sowing of crop plays an important role in determining the performance of a crop and pearlmillet is not an exception. In rainfed areas, the sowing of pearlmillet should be commenced with the onset of monsoon shower. Sowing at the optimum time gives maximum grain yield, net profit and reduces the chances of disease and pest incidence. A maximum temperature range of 28-32°C is found to be optimum for proper growth in the initial stages and to achieve this, the crop should be sown by the first fortnight of July. Late sowing in the month of August causes poor stand of the crop due to high rate of mortality of the seedlings, restricted vegetative growth of the crop, poor grain setting and higher incidence of diseases due to comparatively low temperature during the period. Delay in sowing lowers the grain yield considerably; the rate of decline varies from 40 to 80 kg/day/ha.

*Transplanting:* For delayed sowing, transplanting is recommended in pearlmillet. In intensive irrigated cropping systems, duration of the crop is very important. A period of three to four weeks can be saved by transplanting of the crops. Transplanted pearlmillet performs as good as direct-seeded crop in terms of productivity. For transplanting of pearlmillet, a nursery measuring 500 m<sup>2</sup>/ha area is sown in advance and 3-4 weeks old seedlings are transplanted in the main field in August. A row-to-row spacing of 50 cm and plant-to-plant spacing of 10-12 cm is kept to have 175,000-200,000 plants/ha. A rainy day is generally preferred for transplanting. Irrigation is necessary for transplanting, if there is no rain.

*Seed rate and plant population:* The general recommended seed rate of pearlmillet is 4-5 kg/ha; however, experimental results indicate that optimum seed rate for sandy soils of Rajasthan is 4.5 kg/ha, while it is 3 kg/ha for black soils with higher moisture-retention capacity. A row-to-row spacing of 45 cm is adequate for drilling. Plant-to-plant spacing is determined 3 weeks after sowing, i.e. at the time of thinning and weeding. The optimum plant population is 175,000-200,000/ha. However, a plant population of 160,000/ha should be maintained in erratic rainfall areas. Seeds of pearlmillet should be sown about 2-4 cm deep preferably by drill or with plough by *kera* method.

### WEED MANAGEMENT

As pearlmillet is grown predominantly in warm rainy season, weeds of different kinds deprive the crop of vital nutrients, moisture, light and space. Like other rainy-season crops, pearlmillet faces severe weed competition leading to heavy reduction in grain yield. Competition with weeds could reduce yield by 25-50%. Weed competition is acute during early stage of pearlmillet when the crop growth is relatively slow. Critical period of weed competition is up to 35 days after sowing. The important weeds in pearlmillet are: *sathi* (*Trianthema portulacastrum*), *kewai* (*Digitaria sanguinalis*), *makra* (*Dactyloctenium aegyptium*), anjan grass (*Echinochloa ciliaris*), doob (*Cynodon dactylon*) and



*motha* (*Cyperus rotundus*). Witch weed (*Striga* sp.), a partial root parasitic weed, also causes severe losses to the crop.

Manual weeding is a costly affair and also at times becomes difficult because of soggy nature of soil during the crop season. Pre-emergence application of atrazine @ 0.5 kg a.i./ha controlled 71-96% of the broad-leaved weeds and increased the yield by almost 30-40% over the unweeded control (Gautam and Kaushik, 1980). In addition to that one manual weeding was also recommended to uproot the perennial weeds like *Cynodon dactylon* and *Cyperus rotundus*. Other than atrazine, pre-emergence application of simazine (1.0-1.5 kg a.i./ha) and pendimethalin (0.75-1.5 kg a.i./ha) also gives fairly good control of a wide spectrum of weeds without affecting pearl millet. For light soils, terbutryn or propachlor (1.0-2.0 kg a.i./ha) are recommended for pre-emergence application. Norea or fluometuron (1.0-1.5 kg a.i./ha) is recommended for pre-emergence application in heavy soils. For controlling late-emerging broad-leaved weeds and many annual grasses post-emergence application of 2,4 DEE (0.25-0.5 kg a.i./ha) is recommended.

### NUTRIENT MANAGEMENT

**Chemical fertilizer:** It is estimated that for production of 1 tonne grain, pearl millet requires 36 kg N, 8 kg P and 34 kg K (Table 5.5). The utilization efficiency of applied N, P and K from fertilizer by pearl millet is about 36, 20 and 126% respectively. These figures may change with the texture of the soil.

Fertilizers not only increase above-ground growth but also enhance below-ground root proliferation. In this way, replenishment of the soil nutrients encourages more efficient water use. Of the 3 macro-elements, response to N is almost universal in the country. The output : input ratio of nitrogenous fertilizers ranged between 0.8 and 2.7 in different zones (De and Gautam, 1987). In a study at IARI, New Delhi (Table 5.6), the optimum dose of N was found to be 60 kg N/ha (Gautam, 1997). The studies aimed at determining response to N fertilization of newly developed hybrids and open-pollinated varieties under varying dates of sowing showed that most of the cultivars were responsive to N fertilization. Application of 40 kg N/ha in Zone A (Rajasthan and Gujarat) and 60-80 kg N/ha in Zone B (Haryana, Western Uttar Pradesh, North Madhya Pradesh and Maharashtra) were found optimum for both hybrids and open-pollinated varieties under rainfed conditions. Nitrogen should be applied in 2 equal splits, i.e. half at sowing and the rest half as top-dressing 3-4 weeks after sowing, subject to the availability of soil moisture. Split application saves N losses due to leaching particularly in light soils.

Use of nitrogenous fertilizers helps in realizing maximum protein potential of pearl millet. Application of 80-120 kg N/ha enhanced protein content by 50%,

**Table 5.5** Primary nutrient removed by the *kharif* cereals

Crop	Nutrients removed (kg/tonne)		
	N	P	K
Pearlmillet	6.69	2.45	22.54
Sorghum	9.28	3.21	15.35
Maize	8.20	3.10	17.70

Source: FAI (1996)



**Table 5.6** Grain yield of pearlmillet as influenced by levels of N at New Delhi in different years

N (kg/ha)	Grain yield of pearlmillet (tonnes/ha)			
	1993	1994	1995	Mean
0	1.47	2.58	1.62	1.89
30	1.96	3.15	2.27	2.46
60	2.39	2.75	2.51	2.88
90	2.58	3.67	2.73	3.00
CD ( $P = 0.05$ )	0.194	0.279	0.212	-

Source: Gautam (1997)

methionine and tryptophane by 30-50% but did not affect the leucine content. Some reports indicate that application of 30-90 kg N/ha increased prolamine but decreased glutenin content of pearlmillet. Pearlmillet also responds to phosphorus on P-deficient soils. At the IARI, New Delhi, additional grain yield of 800 kg/ha was obtained by adding 20 kg  $P_2O_5$ /ha. In another trial, yield response to applied N increased considerably with the increasing rate of phosphorus application. Increase in nitrogen beyond 80 kg N/ha without phosphorus reduced the yield. The recommended levels of phosphorus for pearlmillet crop is 20-40 kg  $P_2O_5$ /ha.

Though the crop is copious user of potash, more than maize or sorghum at comparable yield levels, no noteworthy response to applied potash has been observed. However, at places like Raichur, Junagadh, Coimbatore and Jammu, a response of 1.2 tonnes/ha was obtained to an application of 90 kg  $K_2O$ , while it ranged between 0.19 and 0.22 tonne/ha at Rohtak and Tonk. Application of P and K fertilizers should therefore be based on soil-test recommendations. The general NPK recommendations to pearlmillet are 40-60 kg N + 30-40 kg  $P_2O_5$  + 30-40 kg  $K_2O$ /ha. All P and K should be applied (band placed) before sowing. The placement of these fertilizers increases the efficacy of applied fertilizers.

### Micronutrients

Irrigated pearlmillet responds to Zn application up to 25 kg  $ZnSO_4$ /ha. Since the crop is grown in intensive cropping systems involving rice or wheat, the residual zinc after these crops can meet the needs of pearlmillet. If deficiency symptoms are observed in standing crop, it can be corrected by foliar application of 0.5%  $ZnSO_4$  with 0.25% lime solution.

### Organic manures

A good response of pearlmillet to application of bulky organic manures such as FYM, compost and vermicompost has been reported for all the pearlmillet-growing areas. Bulky organic manures supply not only macronutrients but also micronutrients. Besides nutrient supply, bulky organic manures are very effective in improving the moisture-holding capacity of the soil. Long-term experiments reveal that application of 2.5 tonnes of FYM for zone A and 5.0 tonnes of FYM for zone B every year in combination with 40 kg N/ha was helpful for yield stability in pearlmillet.



**Biofertilization**

Experimental evidences indicate that inoculation of pearl millet seed with the strains of the *Azotobacter* or *Azospirillum* increased the yield markedly (Bana and Gautam, 2009; Reddy and Reddy, 2010). Seed inoculation with *Azospirillum* in conjunction with 10-20 kg/ha N fertilizer can save N to the extent of 10-20 kg/ha.

**WATER MANAGEMENT**

Pearl millet is generally grown during the *kharif* season under rainfed condition in areas of low rainfall. It is given supplemental irrigation when long spells of drought prevails, provided irrigation water is available. The crop is grown primarily in dry farming areas. Water requirement of this crop is much lower (250 mm – 350 mm) than maize, sorghum and finger millet (500-600 mm). Though pearl millet is a rainfed crop, irrigation at anthesis or flowering stage is beneficial. Two irrigations involving 12.4 cm water at 75% soil water availability in the top 30 cm of soil layer have been observed as optimum for the *kharif* crop. As many as 3 to 4 irrigations are required in the event of complete failure of rainfall.

It has been estimated that pearl millet requires, on an average, 140-150 mm of water per metric tonne of grain. This calculation is based on the fact that soil moisture is properly utilized and there is no disease or pest incidence, no nutrient deficiency and no washing out of the pollen by the late rains. Utilization of rain water varies with the type of soil, organic matter content in the soil, levelling of the field and moisture-conservation practices followed in that field. A rainfall of 500 mm received during the crop season would be able to produce the grain yield varying from 1 to 3.5 tonnes/ha.

**Moisture-conservation practices**

Since pearl millet is a rainfed crop moisture conservation is utmost important for a good harvest. Some moisture-conservation practices are given below.

- Deep ploughing once and 3-4 ploughing before sowing to increase rain-water infiltration into soil.
- Application of FYM or compost @ 5 tonnes/ha to improve moisture-holding capacity of soil; it also reduces the soil temperature by 3-4°C.
- Ridge and furrow system of planting to minimize surface runoff and better water harvesting.
- Use of mulches (wheat straw, FYM, stover etc.) to check the evaporation losses.
- Use of different kinds of transpiration suppressants, e.g. kaolin, atrazine.
- Removal of one-third upper part of the seedlings to minimize the transpiration losses.
- Seed treatment with NaCl or KNO<sub>3</sub> (0.2%) to give hardness to the crop plant.
- Reduction of plant stands according to the degree of drought.
- Appropriate weed-control measures.
- Breaking of upper crust of the soil layer to check the evaporation losses.
- Intercropping with legumes or other crops to provide soil cover during early stages of crop.
- Removal of unhealthy seedlings to reduce water loss through transpiration.



## CROPPING SYSTEMS

### Sequential cropping

In northern India many rotations with pearlmillet are adopted. In states like Rajasthan and Gujarat, where rainfall is scanty most part of pearlmillet area is covered with 100% cropping intensity which means only one crop is grown in one calendar year and in these areas therefore pearlmillet monocropping is practiced. At Delhi the grain yield of pearlmillet in pearlmillet-legume sequential cropping (Giri and De, 1979) was increased by 23% when grown after groundnut, 24% after cowpea and 12% after pigeonpea. This grain yield increase was equal to that obtained with 60 kg N/ha. Rajasthan and Gujarat farmers should therefore practice pearlmillet-legume cropping system. But pulses and oilseed legumes (soybean/groundnut) are also more profitable than pearlmillet.

In assured rainfall areas pearlmillet is followed by a *rabi* crop and general rotations are: pearlmillet-barley, pearlmillet-wheat and pearlmillet-toria etc. In these rotations, pearlmillet is grown as a rainfed crop and the *rabi* crop is grown on conserved moisture. One or two irrigations are recommended to the *rabi* crops if conserved moisture is not sufficient for the entire crop season. Such rotations (200% intensity) are most popular in western Uttar Pradesh, northern Madhya Pradesh, Maharashtra and Haryana.

### Intercropping

For intercropping in pearlmillet, paired-row planting is preferred in place of uniform rows. Spacing of 30/70 cm is the most appropriate one where pearlmillet is sown in paired rows at a distance of 30 cm and the spacing of 70 cm is kept between the two paired rows, where an intercrop is sown. In rainfed areas intercropping is an insurance against bad weather. Selection of intercrop is generally from oilseeds and legume crops. Most suited intercrops from the legume group are: greengram, blackgram, pigeonpea, cowpea, and clusterbean (Table 5.7). Intercrops from oilseed group are groundnut, sesame, castor and soybean. Intercropping in pearlmillet generally increases the land-equivalent ratio (LER) and monetary returns considerably.

Intercropping not only stabilizes yields but also maximizes total productivity/unit area under normal climatic conditions. The basic concept of

**Table 5.7** Ideal companion crops for intercropping identified at different centres

Region/Centre	Suitable intercrops
Mandor, Jaipur, Fatehpur-Shakhawati	Pearlmillet + mothbean/clusterbean
Hisar, Jamnagar and Madhuri Kund (Uttar Pradesh)	Pearlmillet + greengram/sesame
Delhi	Pearlmillet + groundnut/pigeonpea/castor
Gwalior	Pearlmillet + blackgram/soybean
Bijapur, Pune, Aurangabad and Coimbatore	Pearlmillet + pigeonpea, Pearlmillet + groundnut/cowpea/ Sunflower

Source: Bhatnagar *et al.* (1998)



intercropping is that 2 or more species can exploit the environment better than either of the species grown individually.

Data for All India Coordinated Project on Improvement of Pearlmillet on intercropping (AICMIP, 1991, 1992, 1996) revealed that pearlmillet yield did not vary much due to intercropping. Promising intercrops in the intercropping were groundnut, mungbean, pigeonpea and castor which gave 0.23–0.35 tonne/ha additional yields to the growers. Most promising and remunerative mixtures in different agro-climatic regions were pearlmillet + cowpea, pearlmillet + pigeonpea, pearlmillet + groundnut, pearlmillet + mungbean, and pearlmillet + sesame (Table 5.8).

**Table 5.8** Yield and net returns in pearlmillet based intercropping system

Intracropping system	Grain yield			Pearlmillet-equivalent (tonnes/ha)	Mean	
	Data of 4 years at following no. of centres	Pearlmillet (tonnes/ha)	Intercrop (tonnes/ha)		Input in intercropping (₹/ha)	Net return from intercropping (₹/ha)
Pearlmillet + cowpea	6	2.5	0.35	3.46	6,055	1,680
Pearlmillet + mungbean	7	2.6	0.27	3.40	5,950	1,404
Pearlmillet + urdbean	4	2.5	0.13	2.84	4,970	624
Pearlmillet + castor	3	2.6	0.23	3.16	5,530	920
Pearlmillet + sesame	4	2.2	0.17	2.90	5,075	1,241
Pearlmillet + groundnut	5	2.5	0.33	3.29	5,757	1,419
Pearlmillet + pigeonpea	3	2.4	0.24	3.22	5,635	1,512
Pearlmillet alone	8	2.6	-	2.64	4,620	-

Source: Gautam (1995)

## DISEASES AND THEIR MANAGEMENT

### Downy mildew

Downy mildew (*Sclerospora graminicola*) causes yield losses varying from 5 to 60%. Symptoms can be observed on 15–20 days old plants. This fungus can be transmitted by oospores on the seed surface or as the mycelium in embryonic tissues of seed. After germination the downy growth of the fungus is seen covering mostly the undersurface of the leaf. Leaves become distorted and wrinkled and tend to split into shreds. Such leaves turn brown pre-mature. The infested plants become dwarf and produce profuse tillering. Affected plants sometimes do not produce earheads. Abnormalities occur in the ear and the whole inflorescence transforms into twisted leafy structure. This gives the ear an appearance of green leafy mass and hence the name 'green ear'.



At present the hybrids and composites developed by the breeders are found to be highly resistant to downy mildew, therefore the incidence of this disease is not a serious problem. Seed treatment with Apron 35 SD @ 8 g/kg seed is quite effective in control of this disease. Infected seedlings should be rogued out and destroyed by burning. Disease-resistant hybrids should be grown. Spray of dithane Z 78 (0.2%) or copper oxychloride (0.35%) has proved effective in controlling the disease.

### Ergot

Sclerotia of ergot disease (*Claviceps fusiformis*) in the soil germinate to produce ascospores which become air-borne and infect individual florets through fresh stigma. Secondary infection occurs by rain or insects or by physical contact among earheads. The optimum conditions for the spread of the disease are high atmospheric humidity, low temperature range (20-25°C) and existence of a high susceptible host. It is a floral disease and appears as small droplets of pinkish or light honey like fluid exuding from the infested spikelets of the ear, which dry-up after a few days and becomes hard. This is called as ergot and contains a poisonous substance which is harmful to man and cattle.

Cultural methods including intercropping, early sowing, adjusting soil fertility and deep ploughing to bury sclerotia have proved to be effective in preventing the disease. Removal of ergot sclerotia by immersing seed in 10% salt solution can minimize the infection. Three sprays of a mixture of ziram 2 g/litre (0.1%) and benlate (0.1%) can reduce the incidence but may not be economical. Host resistance is the best way to control the disease. The cultivars presently in practice possess a good level of resistance against ergot.

### Smut

Chlamydospores of fungus (*Tolyposporium penicillariae*) are responsible for primary infection. Affected ear heads produce a powdery material in place of grains. In the beginning the powder is green but turns dark black on maturity and is responsible for secondary spread of inoculums. Early-flowering panicles are responsible for infection of late flowering ones.

Control measures include removal of infected ears, use of clean seeds, crop rotation and resistance varieties. Some fungicides (Lantavax or vitavax, 0.25%) were found to reduce smut infection when sprayed on to panicles at boot-leaf stage. However, this is not considered as a practical method of control.

### Rust

The symptoms of rust (*Puccinia penniseti*) disease are seen on both surfaces of leaves. The uredinial and telial stages occur on pearlmillet and the spermogonial and aecial stages on alternate host, brinjal (*Solanum melongena*). The rust pustules are small orange and full of spores. On touching these pustules, one can see orange coloured spores sticking on the finger tip. In later stages spores turn black. In severe infection leaves get completely dried.



Control of rust was attained with varying degree of success through fungicides (zineb 0.2% or mancozeb 75 wp) and cultivation methods like adjusting sowing time and fertilizer application. Host resistance is the best remedy in case of rust.

### INSECT-PESTS AND THEIR MANAGEMENT

Important insect-pests of pearl millet are shootfly (*Atherigona approximata*), white grub (*Holotrachia* sp.), grey weevil (*Myloccerus* sp.) and grain midge (*Geromyia penniseti*). However, white grub, shootfly and grey weevil are considered major damaging pests during early growth stages. The seed breeding material, hybrids and composites are screened against a whole spectrum of insect-pests. This has helped in identifying the sources of resistance and also in developing suitable control measures.

#### Shootfly

It is a serious pest in north India. Plants up to three weeks of age are favourite of the pest. The fly lays eggs singly on the lower side of the leaf or near the base of the plants. The maggots travel towards the upper side of leaf and penetrate down the stem and cut the apical growing point of the plant which results in the 'dead heart', whereas in the advance stage they feed on ears and cut off the panicles. Early planting with the onset of monsoon is effective in controlling shootfly incidence. If labour is available, collect and destroy the infested plant parts. Two dustings of malathion (5% dust) @ 25 kg/ha at 10 and 20 days after germination is recommended for controlling shootfly.

#### White grubs

White grubs are very serious and feed on roots of growing seedlings and as a result complete withering of plants occurs leading to low plant stand. Larvae cause the major damage resulting in the complete failure of crop. Grubs cause maximum damage during early stage of crop (July-August). With monsoon showers adults emerge and feed on pearl millet flower and grain at milky stage. Intercropping of pearl millet with pulses like greengram, clusterbean and cowpea can significantly reduce the white grub damage on pearl millet. White grubs can be controlled effectively by treating seeds with chlorpyrifos 20 EC @ 12.5 ml/kg seeds. Soil treatment with phorate (Thimet) 10 G or carbofuran (Furadan) 3 G @ 12 kg/ha with pearl millet seed and applying in furrows at the time of sowing is also quite effective.

#### Grain midge

Grain midge is a serious pest of developing grain in pearl millet. The fly lays eggs in the flowers and the maggots destroy the ovaries. Grainless glumes with white purple case attached to the tip of the spikelet are typical symptoms. Use pure and uniform seeds so that all plants flower at the same time. For controlling midge 250 cc of metacid (50 EC) or 625 CC of thiodan (5 EC) in 250 litres water/ha is sprayed on pearl millet crop. Application of 5% carbaryl is also effective against midge.



**Termite**

Termite (*Odontotermis obesus*) is more serious in dry areas and in the fields where undecomposed FYM is applied before sowing. The pest feeds on the roots and lower portion of the stem of the plant. The attacked plant generally dries up. Apply only well-decomposed FYM in the field to reduce the incidence of termites.

**Grey weevil**

Grey weevil is a minor pest of pearlmillet and application of Quinalphos 1.5%, and fenvalerate 0.4% dust @ 25 kg/ha effectively controls the pest.

**HARVESTING**

Maturity of earheads is not uniform, due to tillering habit of crop. Harvesting at physiological maturity or at a little later stage when grains are hard enough and having nearly 15-20% moisture is ideal. Seeds appear brown at maturity. Harvesting is done by cutting the entire plant or removing the earheads first and cutting down the plants later. The earheads after harvesting should be sun-dried at the threshing floor for 10-20 days. Threshing is done thereafter either by beating the earheads with sticks or under the feet of bullocks. Pearlmillet grains are prone to spoilage during storage. Hence the threshed grain should be cleaned and dried in sun to bring down the moisture content of grain to 12-14% for safe storage. Improved storage structures, viz. metal bins made of GI sheets are suitable for safe storage of grains. The pearlmillet stover is a valuable feed for cattle.

**SUMMARY**

- Pearlmillet is an important crop of rainfed areas. Because of its drought-escaping mechanism it can be grown successfully with rainfall varying from 50 to 1,300 mm.
- In addition to its grain consumption, it is also used as green fodder. Pearlmillet grain is rich in minerals, protein, essential amino acids and fat content.
- India is the largest producer of pearlmillet and Rajasthan, Gujarat, Haryana, Uttar Pradesh and Maharashtra are the leading pearlmillet-producing states of India.
- Pearlmillet is a tall, warm weather, short-day annual plant belongs to family Gramineae (Poaceae).
- It is a cross-pollinated crop and the chromosome number is  $2n=4$ . The gynoecium is protogynous, and the grains are caryopsis.
- Life cycle is characterized by the following sequential developmental stages: germination, seedling emergence, seedling establishment, tillering, final leaf stage, booting, panicle emergence, half bloom stage, fertilization, seed set, milking, soft dough stage, hard dough stage and physiological maturity.
- Pearlmillet requires a fine and smooth seedbed. Summer ploughing every year and deep ploughing once in 3-4 years are recommended. A temperature



range of 28°-32°C is found to be optimum for proper growth in the initial stages and to achieve this, the crop should be sown by the first fortnight of July.

- Delay in sowing lowers the grain yield considerably; the rate of decline varies from 40 to 80 kg/day/ha. For delayed sowing, transplanting is recommended in pearl millet. To maintain plant population of 175,000-200,000/ha the 4-5 kg/ha seed rate and row-to-row spacing of 45 cm is optimum.
- Pearl millet faces severe weed competition leading to heavy reduction (up to 25-50%) in grain yield. Critical period of weed competition is up to 35 days after sowing. In addition to one manual weeding uprooting of the perennial weeds is recommended.
- For herbicidal weed management pre-emergence application of atrazine @ 0.5 kg a.i./ha is found to be effective. Pre-emergence application of simazine (1.0-1.5 kg a.i./ha), pendimethalin (0.75-1.5 kg a.i./ha), terbutryn or propachlor (1.0-2.0 kg a.i./ha), Norea or fluometuron (1.0-1.5 kg a.i./ha) also gives fairly good weed control.
- For controlling late-emerging weeds post-emergence application of 2,4 DEE (0.25-0.5 kg a.i./ha) is recommended.
- For production of 1 tonne grain, pearl millet requires 36 kg N, 8 kg P and 34 kg K. Application of 2.5-5.0 tonnes of FYM every year in combination with 40 kg N/ha is helpful for yield stability in pearl millet.
- The general NPK recommendation of pearl millet are 40-60 kg N + 30-40 kg P<sub>2</sub>O<sub>5</sub> + 30-40 kg K<sub>2</sub>O/ha. Pearl millet responds to Zn application up to 25 kg ZnSO<sub>4</sub>/ha. Seed inoculation with *Azospirillum* or *Azotobacter* saves 10-20 kg/ha N.
- Though pearl millet is a rainfed crop, irrigation at anthesis or flowering stage is beneficial, if there is moisture stress. Use of mulches, transpiration suppressants, ridge and furrow system of planting, application of organic manures, appropriate weed control, deep ploughing, breaking of upper soil crust are some of the very important practices for moisture conservation.
- Downy mildew, ergot, smut and rust are the major disease of pearl millet, which are controllable by adopting crop rotation, deep summer ploughing, timely sowing, growing disease-resistant varieties, appropriate seed treatment and spraying of fungicide.
- Important insect-pests of pearl millet are shootfly, white grub, grey weevil, chaffer beetle and midge. However, white grub, shootfly and grey weevil are considered major damaging pest during early growth stages.

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## Barley

*Shiva Dhar and Rajendra Prasad*

Barley (*Hordeum vulgare* L.) is an important cereal crop all over the world. Among cereals, it ranks fourth with respect to area and production after wheat, rice and maize. There are evidences to indicate that it is one of the oldest crops known to have been cultivated in India. The sanskrit term 'yava' found in ancient texts refers to barley. It was most likely the principal staple food crop of the Indo-Aryans during the vedic period. It is widely believed that the 'Near East region' is the probable place of origin of barley around 8000 BC (Harlan, 1968). Archeological remains dating back to 8000 BC at Mureybat on the Euphrates in Syria, 6800 BC at Beidha in southern Jordan, 6000-7000 BC at Alikosh (Iran), Ramad (Syria), Jericho (Palestine) and Catal Huyuk and Halcier in Turkey have been found (Harlan and Zohary, 1966). Recent archeological evidences indicate that barley was used as a food source near the site of Aswan dam in Egypt about 16000 BC; much earlier than supposed previously (Wendorf *et al.*, 1979). There is no evidence of whether the inhabitants of the settlement planted and cultured the barley or harvested it from wild stands. Vavilov (1951) has proposed two main centres of diversity, namely, North-East Africa and mountainous regions of Abyssinia for occidental type and South-East Asia, China, Japan and regions adjoining Tibet for oriental type. The barley-producing countries are the erstwhile USSR, Canada, France, Spain, UK, Germany, Turkey, Australia, Morocco and Ethiopia. The demand for barley has been steadily increasing for its use as an animal feed and for various industrial purposes. On the contrary, in India, both the area and production of barley have decreased especially after the introduction of high-yielding varieties of wheat, the cultivation of which is comparatively more remunerative. Besides the price, wheat consumption stands as a symbol of social status. In spite of these situations, barley still occupies a considerable area because of its inbuilt agro-ecological adaptability under a wide range of edaphic and environmental conditions. Barley is also comparatively more tolerant to saline and alkali soil conditions than other winter season (*rabi*) crops. Thus, it can be grown on problem soils where other crops fail to give economic returns. In India, eastern Uttar Pradesh and north-western districts of Bihar comprise the major barley-growing area. In addition to these areas, southern Uttar Pradesh, northern Madhya Pradesh, north-eastern and southern districts of Rajasthan and Haryana,



and hills of Uttarakhand and Himachal Pradesh constitute important producing regions in respect of barley production.

Owing to its very hardy nature, barley is successfully cultivated in adverse agro-environments like drought, salinity, alkalinity etc. in varied topographical conditions like plains and hilly areas under rainfed and irrigated conditions. It is a preferred crop by farmers where wheat cannot be grown due to some agronomic and managerial limitations. It can thus fit in areas having limitations of inputs and environment and unsuitable for other crops. Barley is quite a nutritious cereal. The grains have 8-10% protein, good amount of carbohydrates, minerals and vitamin B complex and forms a staple food for many people in India. The dishes like *chapati*, *sattu* etc. prepared from barley flour are still highly popular. In addition, the energy rich drinks are prepared from the malt extracts of barley. The parched grains of barley are consumed in many parts of Uttar Pradesh, Rajasthan and Haryana. It is preferred to wheat for consumption during summer due to its perceived cooling effect on human body. The consumption of barley is reported to reduce the cholesterol levels in liver and plasma by inhibiting the rate limiting hepatic enzyme  $\beta$ -hydroxy,  $\beta$ -methyl glutaryl Co A reductase. It also stimulates fatty acid synthesis in liver (Foster and Prentice, 1987).

In India about 90% of the barley produced is used for human consumption, while most of it is used as cattle feed in the USA and Europe. While the barley grains make a palatable and nutritious livestock feed, the straw is used as forage and green forage either directly fed to the animals or used for making hay and silage. The grains are also used as feed for pigs and poultry birds. The pork quality is found to improve with barley food and feed to pigs in Europe. Malt is the second largest use of barley and malting barley is grown as cash crop in many developing and developed countries including India. In India about 75% barley is used for feed, 20% for malt and remaining 5% for food purposes. The utilization of barley for malting and brewing industry has picked up recently with an increase of consumption of beer and other malt-based products in many countries including India. The mid-way products of malting find uses in bakery preparations and energy rich foods for human consumption. The end products of malting are used for brewing the alcoholic drinks like beer, whiskey etc. Malting involves germinating barley seeds for a limited period and then drying and lightly cooking the pre-germinated seeds. The product from which the dried rootlet (culms, coombes, cummins, sprouts) have been separated is called malt. Malt is an intermediary in several manufacturing processes, and its types differ depending on their intended use, e.g. the manufacture of malt flours, malt extracts, cereal syrups, various types of distilled spirits, beers and malt vinegar. The malt culms and the residues from these manufacturing processes are used in animal food stuffs (Briggs, 1978) of the total malt produced in India by malting industries, about 60, 25, 8 and 7% is used for brewing, confectionary, distillation and pharmaceuticals respectively.

With the spurt in demand for quality grains of barley for malting industry world-wide, barley production with emphasis on quality aspects may open the floodgates of foreign exchange.



## TAXONOMY AND CLASSIFICATION

Barley, *Hordeum vulgare* L., ( $2n=14$ ) is one of the highly acclaimed members of the family Graminae (Poaceae) and tribe Hordea. It has been classified into different types by different authors depending upon one or many morphological features. Often these classifications overlap one another. However, these help in easy identification of different types of barley. Some of the popular and commonly used classifications are discussed here.

### Classification based on fertility of lateral spikelets

On the basis of arrangement of spikelets on rachis and fertility status, barley has been classified into three different types (i) Two-rowed type: *Hordeum distichon* L.; (ii) Six-rowed type: *Hordeum vulgare* L. emend.; (iii) Irregular type: *Hordeum irregulare* L.

In the two-row barley, the two lateral spikelets are sterile, thus each spike has only two vertical rows of kernels. Generally each spike produces 15 to 30 kernels. In six-row barley both the lateral florets are fertile but their size may vary from slightly to moderately smaller than the central floret. In this type each spikelet consists of one floret with three fertile florets attached to one side of the rachis and three on the other; six vertical rows of kernel are usually produced on each spike. About 25 to 60 kernels are produced on each spike (Delorit *et al.*, 1984). However, in terms of botanical classification it is generally accepted that cultivated barley regardless of kernel row number in the spike, is all one species, namely *Hordeum vulgare* L. (Fedek, 1994). All the truly wild forms of *Hordeum* are two-rowed that is of the four spikelets at each node of the ear, the lateral ones are female-sterile and only the central one develops a grain. Under domestication six-rowed races appeared in which all these spikelets produce grains. There are two genes involved, both with multiple allelic series, but a single recessive mutation ( $vv$ ) is adequate to cause two-rowed barley to become six-rowed. Six-rowed genotypes with fragile ears are known, but do not appear to be truly wild plants and are probably derived from six-rowed cultivars (Harlan, 1976). Irregular barley has fertile central florets; while some of the lateral florets are fertile, others are infertile. This results in the irregular distribution of florets and irregular rows of kernels. Within each of these species there is a number of morphologically distinct forms and these have been given the status of varieties. Whether these should be taxonomically designated variety or form is a moot point, but the natural relationship is indicated by the fact that there is easy exchange of genes between recognizably distinct forms.

### Classification based on awns

On the basis of presence or absence of awns in grains it has been grouped into (i) awned type, and (ii) awnless type.

Again on the basis of nature of awn type they are sub-grouped into (i) smooth awned, and (ii) rough awned.

Awnless types are also called hooded because of the hood-shaped structure that develops in place of awn.



**Classification based on seed coating**

On the basis of presence or absence of seed cover both two rows and six row barleys have been sub-divided into

*Hordeum vulgare* var. *nudum*—naked six-rowed  
*trifurcatum*—hooded six-rowed  
*inerme*—awnless six-rowed  
*hexastichon*

*Hordeum distichon* var. *nudum*—naked two-rowed  
*trifurcatum* -hooded two-rowed  
*inerme* -awnless two-rowed  
*zeocrithon* -fan-tail barley  
*deficiens*

In the varieties *nudum* the caryopsis falls free, in *trifurcatum* the long awn is replaced by an inverted sterile floret which forms a hood (sometimes these forms are called Himalayan barley) and in *deficiens* the lateral spikelets are gone except for the glumes. In the *distichon* types other than *deficiens* the lateral spikelets are represented by sterile, club-shaped structures and the glumes (Berrie, 1977).

**Classification based on adherence of chaff to grains**

- i. Hulled (syn. husked) type: In this type of barley, floral glumes, that is, the husk or chaff remains adhered to the grain. This type of barley does not thresh free.
- ii. Hull-less (syn. naked) type: It is also called naked type of barley. The chaff in this type does not adhere to the grain and therefore the grain can be easily separated on threshing as in wheat.

Like wheat, barley has been classified depending on its reaction to day-length and temperature as winter barley, spring barley and intermediate barley.

All barleys, wild and cultivated belong to the same potentially inter-fertile population, and are grouped under one species *Hordeum vulgare* L. emend. Bowden. The two-rowed barleys are the oldest known types so far. Various genetical, ecological and taxonomic investigations support the conclusion that cultivated barley had a monophyletic origin from a two-rowed species resembling *Hordeum vulgare* ssp. *spontaneum*.

In India it is grown mainly as a *rabi* (winter) crop, except in the high altitude areas of Ladakh and Lahaul, where it is raised during spring season. Although barley is a crop of cool climate, it may be successfully grown in subtropical and tropical conditions. Barley requires a mean daily temperature of about 12°-15°C during the growing season and about 30°C during ripening and maturity. Higher temperatures coupled with dry winds during later stages of crop result in poor grain filling and chaffy seeds causing a lower yield and poor quality grains. The warm and humid climate is suitable for the barley cultivation.

Barley is highly drought tolerant and can be grown with lesser soil moisture. An annual average rainfall of 400-500 mm will result in increased yield. Even a well-distributed and assured rainfall of as low as 200-250 mm is sufficient for raising a good crop of barley.



### DISTRIBUTION AND SPREAD

Barley is spread across the globe in many countries with wide variation in agro-climatic conditions and traditions. Its cultivation extends from the plateaus of Tibet and Ethiopia, to the oasis of Sahara. Barley has been the most-tolerant cereal crop particularly where saline-alkali soils, frost or drought are encountered. Some data on relative tolerance of barley and some other cereal crops are given in Table 6.11. Area, production and productivity of barley in few major countries of the world are given in the Table 6.1. Barley covered about 47.5 million ha with a total production of 123.7 million tonnes, averaging about 2,685 kg/ha in the world during 2009. Among the major countries the Russian Federation led in barley area with 4.94 million ha followed by Ukraine, Australia, Turkey, Spain and Canada. The other countries with substantial area under barley included Kazakhstan, the USA, Germany, Morocco, Iran, France, China, Ethiopia, Syria, UK, Poland, Iraq and India. France had the highest productivity of 6,386 kg/ha among the countries having sizable area under barley cultivation.

**Table 6.1** Area, production and productivity of barley

Continent/countries	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
<i>Africa</i>			
Morocco	1.92	2.57	1,337
Algeria	1.00	1.50	1,500
Ethiopia	1.13	1.40	1,240
Tunisia	0.18	0.24	1,283
Libya	0.19	0.10	547
<i>North and Central America</i>			
Canada	2.39	7.61	3,186
USA	1.00	3.92	3,935
Mexico	0.27	0.67	2,512
<i>South America</i>			
Argentina	0.75	2.98	3,960
Peru	0.15	0.22	1,404
Brazil	0.08	0.27	3,270
Uruguay	0.06	0.19	3,011
Bolivia	0.10	0.08	781
<i>Asia</i>			
Turkey	3.00	7.24	2,414
Iran	1.58	3.21	2,026
China	0.65	2.52	3,877
Kazakistan	1.33	1.31	0,985
Iraq	1.01	1.14	1,131
Syria	1.17	0.90	767
India	0.79	1.60	2,025
<i>Europe</i>			
Russian Federation	4.94	8.35	1,690

Table 6.1 contd

Table 6.1 concluded

Continent/countries	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
Ukraine	4.32	8.48	1,966
Spain	2.88	8.16	2,835
Germany	1.65	10.41	6,298
France	1.58	10.10	6,386
UK	0.92	5.25	5,703
Poland	1.12	3.53	3,158
Belarus	0.68	1.97	2,892
Denmark	0.58	2.98	5,183
<i>Oceania</i>			
Australia	4.09	7.29	1,784
New Zealand	0.05	0.31	5,890
World	47.54	123.70	2,658

Source: FAO, 2009: FAOSTAT([www.faostat.fao.org](http://www.faostat.fao.org))

In India barley occupied an area of 0.62 million ha with a total production of 1.36 million tonnes during 2010-11. The average national productivity was 2,172 kg/ha (Table 6.2). Barley is the seventh important crop in India after rice, wheat, *jowar*, *bajra*, maize and *ragi* in terms of area and production.

Rajasthan tops the barley area with more than 30% of the total area in India. It is followed by Uttar Pradesh, Madhya Pradesh, Haryana and Uttarakhand. The other important states growing barley are Punjab, Himachal Pradesh, Jammu and Kashmir, West Bengal, Maharashtra and Sikkim. The highest productivity was observed in Punjab followed by Haryana. Uttar Pradesh and Rajasthan too recorded higher productivity than the national average. The lowest productivity was noticed in Jammu and Kashmir.

Table 6.2 Area, production and productivity of barley in India

Zone/ States	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
<i>North</i>			
Uttar Pradesh	0.171	0.362	2,117
Uttarakhand	0.024	0.026	1,750
Haryana	0.042	0.137	3,262
Punjab	0.014	0.047	3,357
Himachal Pradesh	0.021	0.016	764
Jammu and Kashmir	0.014	0.008	552
<i>East</i>			
Bihar	0.012	0.013	1,122
West Bengal	0.002	0.002	1,412
Sikkim	0.001	0.001	1,200
<i>West</i>			
Rajasthan	0.223	0.620	2,774
Madhya Pradesh	0.085	0.110	1,297
Maharashtra	0.003	0.001	881
All India	0.624	1.355	2,172

Source: FAI (2010-11)



## THE PLANT

The vegetative portion of the barley plant is similar to that of other cereals except that the auricles on the leaf are conspicuous. Barley is an annual herbaceous plant. Normally its plant height varies from 50 to 150 cm. It is highly variable so far as its different morphological and other characters are concerned.

### Roots

The roots are typically fibrous and non-creeping. Depending on the soil type and moisture availability the lateral spread of the barley roots usually varies from 15 to 30 cm, while the depth varies from 100 to 200 cm. The seminal roots emerge from the radical at seed germination and adventitious roots emerge out from the crown at the time of plant establishment. The root system in barley is adventitious and fibrous. Seminal rootlets (primary or seedling roots) usually 5 to 7 in number emerge from the coleorhiza as soon as the seed germinates. Adventitious (nodal or crown) roots arise from the base of the crown which consists of closely packed basal nodes. These roots grow into the soil and branch thereafter to form a fibrous and branched root mass which extends further into the deeper soil layers. Tillers, if separated from the mother shoot, can grow with the support of its own adventitious roots only. In general, deep growing roots are usually of seminal origin, while shallow roots confined to the upper soil layer are mostly adventitious in nature.

### Stem

The stem is cylindrical culm with series of five to eight cylindrical, hollow internodes distinguished from each other by the nodes or joints. The length of the internodes increases progressively from the base to the top of the plant. The basal internodes are the shortest and in most varieties, each internode is longer than the one below it. The length of culm differs depending on the variety and the growing conditions. A height of 13-153 cm has been observed. In some of the barley varieties, the stem has a purple colour due to the presence of anthocyanin pigment.

The crown carries several culms, a mother shoot or stem and usually two to four tillers. Tillering is a varietal character. However, it is also strongly influenced by the soil condition, level of nutrition, time of sowing and climatic conditions etc. In mutant unicum varieties, normally only the main stem is formed. Two-rowed barleys usually tiller more profusely than the six-rowed barleys. In favourable growing conditions, tillering in barley may continue even after ear emergence. However, the late born tillers do not contribute towards grain production.

### Leaf

Single leaves arise from the nodes alternately on the opposite side of the stem in distichous arrangement. A barley stem may have five to six leaves. They grow upward, rolled up within a tube of other leaf sheaths. Young leaves when looked at from above, form a spiral in a clockwise direction. Each leaf consists



of a sheath, a ligule, and a long blade. The auricles or claws are formed as two lateral projections at the junction of the sheath and blade. The barley leaf blade is much longer than the blade of wheat and the leaves clasp the stem. The sheath is mostly glabrous, however, hairy sheaths are also found in some of the barley varieties. The sheath provides support to the stem. Sheaths lack chlorophyll or stomata and are colourless to purple-red. The angle of the leaf blade with the stem is typical for a variety. Varieties with differing leaf lengths, widths and shapes are known. The last leaf that is the flag or boot leaf is often the smallest of all the leaves. It encloses the ear within its sheath, which swells and is called the boot. Barley leaves have a conspicuous central rib. The plant surface is usually covered with a kind of wax to varying extents, which serves as an inbuilt mechanism to tolerate soil moisture stress.

### **Inflorescence**

The inflorescence of barley is a spike (head or ear) at the tip of the stem. The spike consists of spikelets emerging from the nodes of a rachis. There is a group of three spikelets at each joint of the rachis. These spikelet groups are alternately arranged. Each spikelet consists of two glumes and one floret. In two-rowed barley, only the central spikelet is perfect, while the lateral ones are imperfect. On the contrary in six-rowed barley, all the three spikelets are fertile. The glumes bear awns of varying length in different varieties. The awns may be barbed, semi-smooth or smooth if they have only a few barbs on their tops. The fertile floret carries three stamens and a pistil with a single ovule and a plumose stigma. Two lodicules are located at the base of the pistil. They help in opening of the flower by pushing the palea and lemma apart. Barley is naturally a self-pollinated crop, the occurrence of cross-pollination being extremely low. However, minor alterations in the lodicule's structure permit the opening of the lemma and palea during the flowering and allow up to 5% cross-pollination. As stated earlier, the terms six-rowed and two-rowed barleys refer to the number of grain rows noticeable when the ears are viewed from the top. In some of the six-rowed barley varieties, two lateral rows of kernels in the ear overlap each other, thus permitting the appearance of only four rows of grain in the ear. The genuine four-rowed barley types are rarely found, and if formed the central spikelets are sterile and the lateral spikelets are fertile. The pollen and ovule in each floret mature at the same time. In open- and closed-flowering varieties, the course of flowering differs slightly. Flowering usually starts in the middle of the ear and then spreads both ways. Depending upon the weather conditions blooming occurs mostly between 9 AM and 10.30 AM. Flowering in the whole spike is completed within two to three days.

### **Seed**

The fruit is a caryopsis attached to the lemma, palea and rachilla. In normal hulled barley the lemma and palea (8-15% of grains) remain adhered to the caryopsis after threshing by a cementing substance that is secreted shortly after fertilization. Some varieties have been evolved in which the naked or hull-less grain separates freely from the chaff as in wheat. The grains are about 8-12 mm



long, 3-4 mm wide and 2-3 mm thick. The two-row naked types usually give a uniform plump sample with straight crease in the seeds, whereas the hatched long lateral florets of a six-rowed type are somewhat smaller with a twisted wavy crease. The caryopsis consists of the pericarp, endosperm and embryo. Barley grain is approximately a spindle shaped body, tapering at each end with a shallow furrow running along the ventral side. A naked barley grain appears blue, reddish purple, pale yellow through shades of grey to black or sometimes greenish.

### VARIETAL DEVELOPMENT

The barley-growing area in India has been divided into four major zones based on the agro-climatic conditions prevailing in the area (Ram, 1982). They are:

Hill zone: This includes Himachal Pradesh and hilly areas of Uttarakhand

North-western plains zone: This includes Punjab, Haryana, Delhi, western and central parts of Uttar Pradesh

North-eastern plains zone: This includes parts of eastern Uttar Pradesh, Bihar, West Bengal and Odisha

Central zone: This includes Rajasthan and Madhya Pradesh.

Since the environmental conditions in different zones vary, varieties have been evolved suiting to the needs of each zone. However, there are some varieties which can be used across the zones without sacrificing the yield or quality. Varieties which were in use prior to constitution of All India Co-ordinated Barley Improvement Project by the ICAR in 1967, were mostly tall and low yielding. But later, high yielding varieties having short stature, resistance to pests and diseases and suitability to stressed conditions like late sowing and saline and alkali soils have been evolved. A few varieties have been either introduced or evolved to meet the specific needs of users like for malting. However some old varieties are also popular even now. There is a long list of varieties available for cultivation in different zones. A few prominent varieties suitable for specific purposes and areas most suited for their cultivation with few important characters are listed in Tables 6.3-6.6.

### GROWTH STAGES

Several well-defined stages of growth and development similar to wheat have been noticed in barley. Expression of these different stages of growth and development is regulated by weather, climate, soil moisture, soil fertility, cropping system, prevalence of weeds, pests and diseases and agronomic practices. Thus there may be a slight variation in the stages in different varieties under varying conditions in the same locality. Nevertheless a broad pattern of growth will be similar everywhere.

#### Germination and initial seedling establishment

Germination and initial growth of the barley seed takes place below the soil surface till the coleoptile makes its way up to the soil surface. With the exposure to light, plants become green and start photosynthesis which accelerates the rate of growth and development of leaves. Hereafter, the leaves start appearing in a defined sequence on the mother shoot (main stem). Each leaf is fully visible



**Table 6.3** Barley varieties recommended for different zones

Growing	Variety	Year of release	Zone for which recommended	Developed by
Irrigated	RD 2552	1999	NWPZ, NEPZ	ARS, Durgapura
	PL 751	2006	Central zone	PAU Ludhiana
	BH 902	2010	NWPZ	CCS HAU, Hisar
	NB 2 (NDB 940)	1999	Uttar Pradesh	NDUAT, Faizabad
	BH 393	2001	Haryana	CCS HAU, Hisar
	RD 2592	2003	Rajasthan	ARS, Durgapura
	Jawahar Barley 1	2009	Madhya Pradesh	CoA, JNKV, Rewa
Rainfed (Plains)	K 560	1997	NEPZ	CSAUA and T, Kanpur
	K 603	2000	NEPZ	CSAUAT, Kanpur
	RD 2624	2003	NWPZ	ARS, Durgapura
	RD 2660	2006	NWPZ	ARS, Durgapura
	Getanjali (K 1149)	1997	Uttar Pradesh	CSAUAT, Kanpur
	PL 419	1995	Punjab	PAU, Ludhiana
	JB 58	2005	Madhya Pradesh	COA, JNKV, Rewa
Rainfed (Northern Hills)	HBL 276	1999	Northern Hills Zone	HPKV, Bajaura
	BHS 352	2003	Northern Hills Zone	IARI, RS, Shimla
	BHS 380	2010	Northern Hills Zone	IARI, RS, Shimla
	UPB 1008	2011	Northern Hills Zone	GBPUAT, Pantnagar
	VLB 56	2005	Uttarakhand	VPKAS, Almora
	VLB 85	2008	Uttarakhand	VPKAS, Almora
	PRB 502	2009	Uttarakhand	GBPUAT, Pantnagar

**Table 6.4** Barley varieties suitable for malting and brewing

Variety	Year	Production condition	Area of adaptation	Developed at
AHa 93	1994	Irrigated (TS)	NWPZ	DWR, Karnal
BCU 73	1997	Irrigated (TS)	NWP, NEPZ, PZ	DWR, Karnal
DWR 28	2002	Irrigated (TS)	NWPZ	DWR, Karnal
DWRUB 52	2007	Irrigated (TS)	NWPZ	DWR, Karnal
RD 2668	2007	Irrigated (TS)	NWPZ	ARS, Durgapura
DWRB 73	2011	Irrigated (LS)	NWPZ	DWR, Karnal

**Table 6.5** Barley varieties for cultivation under saline-alkaline soils



**Table 6.6** Barley varieties suitable for dual (grain and green forage) purpose

Variety	Year	Production condition	Area of adaptation	Developed at
RD 2715	2008	Irrigated	Central zone	ARS, Durgapura
BHS 380	2010	Rainfed	Northern Hills	IARI, RS, Shimla
RD 2035	1994*	Irrigated	NWPZ	ARS, Durgapura
RD 2552	1999*	Irrigated	NWPZ	ARS, Durgapura

\*These varieties were released as grain type earlier but recently observed as also good for dual purpose

when the auricle appears. Simultaneously, the crown-root initiation as well as the growth of these roots also takes place. This growth process is accompanied by the emergence of tillers. There may be secondary, tertiary or even quaternary tillers in barley. The leaf sheath begins to grow in length and becomes erect. This stage is marked by the exhaustion of endosperm and initiation of crown-root formation stage and lasts up to 20-25 days after sowing (DAS).

### **Tillering**

The seedling after initial establishment of crown-root system starts tillering. The tillers emerge from the crown and grow along with the main stem. A plant may produce 4-5 productive tillers depending on the variety and environment. In general, two-rowed barley produces more tillers than the six-rowed barley. This phase of growth continues up to 30-35 DAS.

### **Jointing and booting**

This growth process leads to shoot elongation. The first node appears at the base of the shoot and this is followed by the growth of subsequent nodes one after another in succession. Stem elongation takes place during this period. The emergence of the flag leaf or boot leaf virtually marks the termination of the vegetative growth phase. Jointing lasts up to 55-65 DAS. The basal leaves start drying as soon as the ligule of the flag leaf appears. The sheath of the flag leaf is fully visible at this stage and it swells as it embodies the ear inside. This stage is called the booting stage.

### **Heading**

This stage is also known as 'earing' and 'earhead emergence'. The flag leaf gives rise to emergence of ear and the tips of awn become visible in the beginning. Subsequently the full earhead comes out and anthesis begins in the central florets, often with the ear in the boot. Stamens may or may not be exerted. This stage ends with the production of watery ripe grains. The crop remains in this phase up to 75-85 DAS.

### **Ripening**

This stage includes the sub-phases of post-milking, grain filling and grain development. The soft dough gradually turns to hard dough. Barley grains,



initially turn milky ripe and the grains at this stage are very soft. The soft dough stage slowly turns hard and finally the grain attains the dead-ripe stage. This is most important stage of the crop wherein any stress results in substantial reduction in the yield of the crop. Here the neck of the ear continues to lengthen and angle of head to peduncle may change. This stage lasts up to 90-100 DAS. It takes about 25 days from anthesis to maturity.

#### **Maturity and drying**

Once the grains pass the hard dough stage they start losing moisture and plants begin to dry. The plants turn yellowish, loose stiff and become droopy. The physiological maturity of the seed is completed and the crop is ready for the harvest. Delay in harvesting results in loss of grains by shedding of ears, shattering and collapse of stem. This stage is the final stage in the crop life and it depends on duration of the variety and agronomic practices.

### **CLIMATE**

Barley has a wide spectrum of ecological adaptability but it is mainly a crop that grows well in cool climate. The crop requires a minimum annual average assured rainfall of 200 to 250 mm. However, it performs very well as a rainfed crop in regions receiving an average rainfall of 400 to 500 mm. Barley is comparatively more drought resistant than wheat. It is also endowed with an in-built ability to resume growth as soon as soil moisture conditions become favourable after a spell of soil-moisture stress. Barley is grown both in tropical as well as subtropical climates. It requires approximately mean daily temperatures of 12 to 15°C during the growing season and about 30°C for ideal grain maturity. Excessive heat or dry weather after earing precludes normal maturation and proves detrimental to grain quality. Barley is basically a long day plant. Thus a light period of 10-12 hours during vegetative growth and 12-14 hours during reproductive growth is ideal. Of late, with the release of photo-insensitive varieties the criterion of photo-period requirement has been minimized.

### **SOILS**

Barley can be grown on variety of soils ranging from light sandy to heavy clay soils. It performs well on properly drained loamy soils having a pH range of 7-8. Fertile deep loam and well-drained soil is ideal for barley. On heavy soils, its growth is poor and the grain quality is adversely affected mainly due to impeded drainage. Similarly, very light soils are also not suitable as they have a low soil-moisture retentivity. Excessive available N in the soil results in heavy growth and lodging. Hence a medium fertile soil will be ideal for the cultivation of barley. Barley is the most dependable cereal in saline-sodic soil conditions. It can tolerate salinity to a great extent both during germination and later stages of growth. The salt tolerance in barley depends on variety. Barley cannot thrive in acid soils having a pH lower than 6.0 because at this pH, aluminium toxicity increases which in turn retards root growth. Liming at least a month before sowing of barley can correct this toxicity. Liming can mitigate the problem of aluminum toxicity in such soils. There are incidences of boron toxicity in some



cases. So soils having higher available boron content are not suitable for barley cultivation.

### LAND PREPARATION AND SEEDING

The time and extent of tillage is regulated by climate, cropping sequence, and needs of water conservation, erosion control and weed control. In moist, temperate areas complete clearance of crop and weed residues and volunteer plants is desirable. In arid areas trash is left on the surface as a mulch to minimize erosion and evaporation.

Crop residues, weeds, farmyard manure, fertilizers, amendments and chopped straw should be incorporated into the soil. The straw must be fully decomposed before sowing; otherwise the rotting residues may obstruct the emerging seedlings.

Barley may be grown on a rough seedbed and hence one cross cultivation with soil turning plough followed by planting is sufficient to get a good seedbed for sowing. Conservation of late monsoon rains received during August and September is important. In moderately saline-cum-high watertable conditions, the last preparatory cultivation should be given 7 to 10 days before sowing to allow the salts to accumulate near the surface to facilitate sowing of seeds in a relatively less or non-saline soil layer.

For higher productivity it is necessary to have optimum seed rate, spacing, depth and time of sowing. The optimum sowing period for different zones is given in Table 6.7, while the seed rate, spacing and method of sowing for rainfed and irrigated barley is given in Table 6.8.

**Table 6.7** Optimum time of sowing barley in different zones

Zone	Sowing time	Recommended dates
Northern hills zone	Normal	25 Oct. to 11 Nov.
	Late	25 Nov. to Dec.
North-western plains zone	Normal	5 Nov. to 15 Nov.
	Late	10 Dec. to 16 Dec.
North-eastern plains zone	Normal	15 Nov. to 25 Nov.
	Late	10 Dec. to 16 Dec.
Central zone	Normal	12 Nov. to 18 Nov.
	Late	2 Dec. to 10 Dec.

**Table 6.8** Seed rate, row spacing, depth and methods of sowing barley for rainfed and irrigated conditions

	Rainfed	Irrigated-normal sowing	Irrigated-late sowing
Seed rate	100 kg/ha	75-80 kg/ha	100-120 kg/ha
Row spacing	22.5-25.0 cm	22.5 cm	20.0-22.5 cm
Depth	6-8 cm	4-5 cm	4-5 cm
Method of sowing	Sowing in rows by bullock-drawn <i>desi</i> plough/seed drill	Sowing in row by bullock-drawn <i>desi</i> plough/seed drill/ tractor mounted seed drill	Same as in irrigated condition



In general, depth and method of sowing may change depending on the soil condition and moisture content in the soil. The time for sowing barley depends on the source of water supply. The rainfed crop sowing commences from the end of October and should be completed latest by the first week of November. At the time of sowing, the soil should have sufficient soil moisture conserved from the preceding rainy season. Under irrigated conditions sowing commences from the middle of November and continues up to the first week of December. Barley can be sown up to the first week of January in irrigated areas. However, a suitable variety should be selected for late-sown conditions.

### NUTRIENT MANAGEMENT

#### Organic manures and crop residues

Since barley is grown in soils low in fertility, affected with salt problems and under dryland conditions, application of farmyard manure (FYM), organic manures, crop residues etc. improves the water holding capacity and fertility status of the soil. Besides, it also increases the buffering capacity of the soil. Application of well-decomposed and friable farmyard manure free from pathogens, insects' eggs and toxic substances @ 10-15 tonnes/ha about a month prior to sowing and incorporating it in the soil improves the soil condition resulting in higher productivity of barley.

The tall varieties of barley usually lodge at high levels of nitrogen and their response to nitrogen is low. However, the development of dwarf varieties of barley has removed this impediment. Fertilizer doses can be adjusted according to the targeted yield under the optimum growing conditions. The improved high-yielding, dwarf and semi-dwarf varieties of barley are quite responsive to fertilizer management. Hence a fertilizer package tailored on soil-fertility status, irrigation facility and targeted yield results in highly satisfactory productivity in barley (Mishra *et al.*, 1979).

The deficiency of nitrogen in barley limits the growth of roots and shoots. It reduces and retards tillering, results in small and thin (weak) shoots, sparse pale green leaves, small ears, and hastens grain maturity. On the other hand, excess nitrogen leads to disproportionate vegetative growth, lodging, and delays crop maturity. Under irrigated condition, one-third of total nitrogen and full quantity of phosphorus and potassium should be given at the time of sowing either through draw tube (*pura*) attached to seed drill or behind plough and mixed in the soil. The next one-third of nitrogen should be given after first irrigation which helps in the tiller growth and development. The last dose of nitrogen should be given when the crop has entered in the flowering stage. The high-yielding hull-less varieties need higher doses of nitrogen as compared to hulled varieties. Under rainfed dryland agriculture condition all fertilizer is applied at sowing. Nitrogen dose for the barley grown for malting purposes is also low to keep the protein content at an acceptable low level.

Phosphorus deficiency restricts growth and the colour of the leaves turn bluish-green. Finally, the tips of these leaves become brown and they subsequently dry up. Severe deficiency of phosphorus leads to the production of purple anthocyanin pigments on leaves, stems and ears.



Potassium is generally not recommended, but may be added as per soil test recommendation.

General fertilizer application recommendations for barley under different growing situations are:

Rainfed conditions	: 40 kg N + 20 kg P <sub>2</sub> O <sub>5</sub> /ha
Irrigated timely sown	: 60-80 kg N + 30 kg P <sub>2</sub> O <sub>5</sub> /ha
Irrigated late sown	: 50-60 kg N + 30 kg P <sub>2</sub> O <sub>5</sub> /ha

Barley grown with the purpose of using grains for malting needs a different management strategy. To maintain the protein content at required level both fertilizer and irrigation should be given cautiously. Nutrients should be balanced like 50:25:25 kg NPK/ha and all the nutrients should be given at the time of sowing. No top-dressing should be made, as it results in higher protein content in grains.

### WATER MANAGEMENT

Basically barley is a winter season drought tolerant crop having limited water requirement. As barley has initial vigorous growth, its root system proliferates deeper into the soil and extracts moisture. However, providing irrigation is quite useful in increasing yield from fertilizer responsive short statured dwarf and semi-dwarf varieties. The quantity and frequency of irrigation to barley depends on the late rains, soils and climatic conditions.

Barley uses water more efficiently than other winter cereals. It has a much better ability to resume growth after a short spell of soil-moisture stress. The frequency and the depth of irrigation water depend on the quantum and distribution in winter rainfall, soil conditions, and the nature of the variety grown. Sufficient soil moisture should be ensured at sowing to attain an uniform as well as recommended optimum plant density. The careful selection of cropping and cultural practices and their appropriate combination is required to conserve sufficient moisture in soil for barley in the *rabi* season.

#### Hulled barley

If barley is grown under irrigated condition a pre-sowing irrigation will result in better seedling establishment. It is reported that about 50% available soil moisture gives satisfactory germination and irrigation at 25% available moisture in 15-30 cm soil layer results in higher yields. Irrigation based on critical stage approach has been found to be economical and effective (Singh and Sandhu, 1981). The following stages have been identified as critical for irrigation.

Active tillering	: About 30-35 DAS
Flag leaf/booting	: About 60-65 DAS
Milk/grain filling	: About 80-85 DAS

If only one irrigation is available it should be given at active tillering and if two irrigations are available they should be given at active tillering and milk stages. Further irrigation at 0.45-0.50 atmosphere soil-moisture tension has been reported to give higher yield of barley in late-sown conditions. In dry land



conditions too, one life-saving irrigation at a critical stage will increase yield substantially. On saline-sodic soils, water-logging is a formidable problem. Therefore, light but frequent irrigations instead of heavy irrigations at longer intervals should be given.

#### **Hull-less barley**

Since hull-less barley varieties require about 10 to 15 days more for maturity than the hulled type, they may be caught in the hot winds in the plains during maturity. This results in poor grain filling in the upper portion of earhead and reduction in the grain yield. Therefore it is essential to give one more irrigation at grain-filling stage to avoid the effect of hot winds at the time of grain filling.

#### **Fodder and forage barley**

When barley is grown for fodder and forage purpose, the first cut or harvest should be done at about 60-65 DAS. While taking a cut, care should be taken to leave about 2.5-3.0 cm above-ground plant parts to give better regeneration power to crop. Also application of 20 kg N/ha and giving one irrigation is essential to have better and vigorous growth after the cut.

#### **Malt barley**

One extra irrigation given at grain filling results in better quality grains for malting. At no stage of crop, moisture stress condition should be allowed to set in.

### **WEED MANAGEMENT**

Barley is relatively more competitive to the weed flora commonly associated with it due to its quick initial growth rate and a thick plant stand. It almost covers its growing area by active tillering stage. This initial fast growth gives it upper hand in competing with weeds and under ideal conditions of growth it almost smothers all the weeds and survives from competition. Thus the weed problem is less in barley. Nevertheless, the improvement in barley with higher doses of fertilizers under irrigated conditions has prompted weed competition too. The most common weed species identified in barley are: *Avena fatua* (wild oat), *Phalaris minor* (canary grass), *Fumaria parviflora*, *Chenopodium album* (bathua), *Cirsium arvense* (kateli), *Anagallis arvensis* (krishna neel), *Melilotus alba*, *Melilotus indica* (senji), *Convolvulus arvensis*, *Ageratum conyzoides* etc.

A good cultural practice like one hoeing and one hand weeding after first irrigation at 30-35 days after sowing gives effective control. If weeds persist, chemical weed control may be contemplated. All broad-leaved weeds can be controlled by spraying 2,4-D @ 0.75 kg a.i./ha dissolved in 750 litres of water at 40-45 DAS. Under dryland conditions the dose may be reduced to 0.50 kg. Addition of 3% urea solution to 2,4-D spray mixture improves its efficacy. Application of isoproturon @ 1-1.5 kg a.i./ha or methabenzthiozuron @ 1.5 kg a.i./ha or metaxuron @ 1.5 kg a.i./ha dissolved in about 750 litres of water as



post-emergence spray at 30-35 DAS effectively controls grassy and other weeds. Major weeds associated with barley and their chemical control measures are given in Table 6.9.

**Table 6.9** Different types of weeds and their chemical control methods

Type of weeds	Herbicides	Dose/ha	Method of application
Broad leaf	2,4-D	500 g	Spray around 35 days after seeding using 400-500 litres water
	Metsulfuron	4 g	
Both narrow and broad leaf	Isoproturon	750-1,000 g	Spray around 35 days after seeding using 400-500 litres water
	Isoproturon +2,4-D	750 + 500 g	
	Pendimethalin	1,000-1,500 g	Spray pre-emergence using 400-500 litres of water

### PEST CONTROL

Barley crop is infested by number of pests in different areas depending on climatic conditions. The soil-borne pests, like cereal cyst nematodes, are area specific and spreads only through soil. These cause damage ranging from moderate to heavy, depending on variety, method of cultivation and agro-climatic conditions.

#### Insect-pests

The following insect-pests have been reported to cause damage in barley in several areas warranting preventive and control measures.

**Termites:** There are two species of termites noticed in barley, namely *Microtermes obesi* and *Odontotermes obesus*. Termites attack the root system of plant and plants start showing wilting symptoms and later on dry up. Deep ploughing during fallow period and exposing the termites to sunlight limits the attack. Seed treatment is suitable with 4 ml Dursban/Ruban/Durmet 20 EC (chlorpyrifos) or 6 ml Regent 5% sc (Fipronil)/kg seed. If attack of termite is seen in a standing crop chlorpyrifos @ 3 kg/ha mixed with 50 kg soil should be evenly broadcast in the field. This method is suitable for rainfed crop. In irrigated barley light irrigation may be applied after broadcasting the insecticide.

#### Aphids

Aphids (*Rhopalosiphum maidis*) are small green to dark coloured, spiny insects swarming around all parts of plant and sucking the sap. Subsequently infested plants turn pale green and remain stunted. They also serve as vectors for virus causing barley yellow dwarf disease. The aphids in barley may be controlled by spraying imidachlorprid 200 SL or 20 g Thiamethoxam 25 WG or 12 g dantop (Clothianidin 50 WDG) or 150 ml rogor 30 EC in 300 litres water/ha. The spray may be repeated in case there is re-occurrence or incomplete control at 10-15 days interval. The aphid may be controlled at earhead stage at

economic threshold level of 5 aphids/earhead. Since aphids appear first on borders of the field, the spray should be done only in the infested strips to check their further spread.

### DISEASES AND THEIR MANAGEMENT

Following diseases have been commonly observed in barley (Suryanarayana, 1979):

Rusts:	Yellow rust ( <i>Puccinia striiformis</i> ) Black rust ( <i>Puccinia graminis tritici</i> ) Leaf rust ( <i>Puccinia hordei</i> )
Smuts:	Loose smut ( <i>Ustilago hordei</i> ) Covered smut ( <i>Ustilago nuda</i> )
Leaf spots:	Net blotch ( <i>Helminthosporium teres</i> ) Spot blotch ( <i>Helminthosporium sativum</i> ) Stripe disease ( <i>Helminthosporium gramineum</i> )
Mildew:	Powdery mildew ( <i>Erysiphe graminis</i> )
Foot rot:	<i>Fusarium culmorum</i>
Molya:	<i>Heterodera avenae</i>

Among the above yellow rust, smut and stripe diseases are important in plains, powdery mildew is important in the hills and foot rot is important in non-traditional saline areas of Bihar and West Bengal. Molya, which is caused by a nematode has been more serious in Rajasthan.

#### Rusts

Barley gets all the three type of rusts but relatively yellow (stripe) rust is more important in NH and NWP zones. The brown (leaf) rust is of the equal importance in NWP and NEP zones. Black (stem) rust is of more significance in southern hills and adjoining peninsular zone. The yellow rust is identified by parallel rows of pale to orange-yellow pustules that occur in rows on the foliage, stems or ears and may be close enough to appear as continuous stripes. Leaves may wither early; grains are shriveled and small. The black stem rust is identified by reddish brown rows of spots on stems and leaves.

The brown (leaf) rust is identified by numerous small, round yellow to orange-brown pustules scattered over leaf blades and sheaths. The uredospores spread the disease.

The rusts are controlled by growing resistant varieties, removal of alternate hosts of causal organisms. Seed treatment with fungicides like vitavax or raxil @ 1.5 g/kg seed is effective for controlling rusts. For yellow rust, grow resistant varieties or those which are less affected like PL 807, DWRUB 52, VJM 201, PL 426, PL 419 and PL 172.

#### Smuts

In loose smut, the entire ear except the rachis, is replaced by brown, enclosed spore masses. Ultimately the spores are liberated and blow away and the naked rachis remains. When the spores reach new ears they infect the developing grain.



In covered smut, the disease is noticeable only when the heads emerge from the boot, and it is seen that the grains are replaced by hard black spore masses, each covered with a thin membrane. Membrane begins to split after emergence and spores are blown to healthy ears. Spores also breakup and spread during threshing and contaminate the grain.

Smut is controlled by growing resistant varieties, seed treatment with fungicides like vitavax or raxil @ 1.5 g/kg seed. Removing and destroying the affected ears reduce the build up of inoculum of fungus for the next season and further spread.

### Leaf spots

Net blotch results in lesions on leaves as brown net like blotches or dark brown lines in lighter brown zones or long, narrow rectangular or irregular stripes. Infected stems show brown discolouration. Light brown blotches occur on the kernels. Grains are reduced in size.

Spot blotch is identified by dark brown, rotting lesions on the roots and seedling mortality. Often the plants grow, and the fungus spreads slowly through the tissues forming dark brown, elliptical spots and blotches on the leaf blades, stalks and glumes. Diseased plants may be stunted and excessively tillered. Leaves tend to dry and wither away early.

Barley stripe is identified by long narrow, brown or yellow stripes; as many as seven stripes may run nearly the length of the plant. Leaves may split fray and collapse. Even if the plant is not killed there will be reduction in vigour. Ear head emergence may be affected or it may emerge with no grain. If grains are formed they will be discoloured and infected.

Use of resistant varieties, clean and treated seeds with organo-mercurial compounds like vitavax or raxil @ 1.5 g/kg seed, and crop rotation reduce the incidence of blotch and stripe diseases.

### Mildew

The first signs of infections in powdery mildew are the appearance of small white/grey fluffy spots of mycelium on leaf sheaths, leaf blades or on the ears. These grow dark and become powdery with spores. Later small, round, black reproductive bodies, the perithecia, may be formed on the mycelial mats. Disease development is favoured by rapid lush growth of the crop.

Control measures include growing resistant varieties, dusting sulphur @ 20 kg/ha and sprays of systemic fungicides like karathane (0.2 %) at an interval of 15-20 days.

### Foot rot

Foot rot disease is identified by discoloured and rotten roots and stunted growth with yellowish leaves. Plants may fail to produce ears, may lodge, may produce dwarfed or distorted heads, which may contain small grains or glumes be empty. White or pinkish spore masses may occur on the heads.

Control of foot rot is difficult. Use of clean and organo-mercurial compound treated seeds, early sowing and good drainage reduce the incidence of foot rot disease.



**Molya disease**

Molya disease is caused by the nematodes. The affected plants occur in patches, and are stunted and yellowish. Tillering is reduced and ears may be shriveled. Attacked plants have many dense, short, thick, highly-branched roots, matted together. The nematodes attack each root near the growing point, growth is arrested and laterals are formed.

Control of this nematode infection is achieved by crop rotation and growing resistant varieties like RD 2052, RD 2035 and RD 2592. Expose the soil to the hot sun during May and June. Apply Furadan 3G @ 30 kg/ha at sowing time to kill the nematode present in the soil.

**HARVESTING**

Barley is ready for harvesting once the plants turn yellow and dry up. The grains become hard and moisture content is around 18-20%. Stem breakdown with slight pressure. High speed winds make plants lean and lodge. Any delay in harvesting results in shattering of ears and loss of grains. Lodging of plants deteriorates the fodder value of crop and at times the quality of the grains gets impaired. The crop is harvested by cutting at ground level by sickles. The harvested product is bundled and moved to threshing yard. It is further dried there and threshed by allowing bullocks to trample or by using stone rollers or mechanical threshers. The grains so threshed are winnowed to separate them from chaff and other admixture of plant parts. Alternatively, the crop is harvested by using the combine harvester wherein the cutting, threshing and winnowing is done at one go. The cleaned grains are dried and a moisture content of about 12% is maintained before being transferred to gunny bags and moved to godown for storage. The straw is collected and kept as 'hay' and is used as animal feed in some areas.

**YIELD**

Recent high-yielding varieties have the yield potential of 4-5 tonnes/ha. However, the straw yield varies depending on plant type and duration of the crop. A tall variety usually produces more straw than dwarf and semi-dwarf varieties. Further, the same variety under late-sown condition may yield lesser straw than timely sown crop. A good crop under normal circumstances may yield about 4-5 tonnes straw/ha in 126 to 132 days duration in northern India. The harvest index depends mainly on three factors, viz. population density, water availability and nitrogen supply (Verma, 1979). On an average, a harvest index of 0.3 to 0.5 has been observed in barley. Barley is mostly grown under rainfed conditions and hence its general level of grain yield is low. The yield of rainfed barley varies from 1.5 to 2.5 tonnes/ha. Barley that is proposed to be used for brewing and distilleries should contain low protein content and hence the use of nitrogenous fertilizers is limited. This results in low grain productivity per unit area. However, it is governed by the levels of agro-practices and the variety besides other factors like climate and soil.



### CROPPING SYSTEMS

Barley has been found suitable for multiple and mixed cropping systems in a variety of conditions. As it is a short-duration crop, it can fit in cropping sequences involving a *kharif* crop in the preceding season and a short-duration crop in succeeding spring and/or summer season. Depending on the assured rainfall or irrigation facility it can be grown in the following sequential cropping systems.

*Cereal-cereal system:* Rice-barley, Maize-barley, Pearl millet-barley, Sorghum-barley

*Legume-cereal system:* Pigeonpea-barley, Mungbean-barley, Black gram-barley, Cowpea-barley

*Miscellaneous system:* Groundnut-barley, Cotton-barley, Sunhemp-barley, Sugarcane-barley, Potato-barley

In some cases even the delay in the harvest of *kharif* crop can be overcome by a successful late barley. Besides the above sequences vegetables-barley is also another important sequence in *diara* lands in eastern Uttar Pradesh and Bihar. Further, wherever there is irrigation, growing of short-duration summer crops like mungbean, cowpea, fodder or forage crops is also possible before going for *kharif* crop.

In addition, barley is also suitable for mixed or intercropping with *rabi* crops like field pea, chickpea, rajmash, mustard /rape-seeds, linseed etc.

### GRAIN QUALITY

Barley flour does not contain gluten and the bread loaf darkens due to the presence of tryosinase enzyme. Large grained two-rowed barley varieties are best suited for milling to make flour. General composition of hulled barley is—carbohydrates 68.0-69.6%, protein 11.5-11.8%, fat 1.0-2.0% and crude fibre 3.9-5.7%.

In general, the quality of hull-less varieties is better than the hulled varieties. Barley grain which are fully mature, medium in size, plump, mallow, free from cuts and blemishes and have a bright golden colour are considered suitable for malting. Agronomic practices like sowing and harvesting at optimum time, balanced fertilization etc., as well as the choice of a suitable variety are basically necessary to produce barley grains fit for perfect malting.

The development of improved varieties for quality purposes always requires identification of important traits affecting quality in a particular growing environment. Since nowhere in India, barley gets long grain-filling period with mild temperatures like in Europe and other temperate countries which grow better malting quality barley, a need was felt to study barley malting quality parameters under Indian environments. It was observed that malting barley traits are not independent and are also influenced by environmental conditions in India. Malt type barley has specific analytical standards. The analytical standards of Indian malt barley are given in Table 6.10.

**Table 6.10** Analytical standards for malt barley in India\*

No.	Parameter	2-row barley	6-row barley
<b>Barley grain</b>			
1.	Moisture (%)	<12.0	<12.0
2.	Kernel shape	Elliptical	Elliptical
	Kernel size	Uniform plump	Uniform Plump
3.	Bold (on 2.5 mm)	90%	80%
	Thin (through 2.2 mm)	<3%	<3%
4.	Skinned/broken grains	<10%	<10%
5.	1,000-grain weight (g)	>45	>42
6.	Husk content	<11.0%	<11%
7.	Protein content (d. b.)**	9.0-11.0%	9.0-11.5%
8.	Germination capacity	>96%	>96%
9.	Germination energy (72hr)	>96%	>96%
10.	Beta glucans	3.7-5.0%	3.7-5.0%
11.	Dormancy	Dormancy to avoid the pre-germination	
<b>Barley malt</b>			
1.	Malt modification	Satisfactory modification with four days germination cycle	
	Malt homogeneity	>90%	>90%
	Malt friability	>60%	>60%
2.	Kolbach index (S/T protein ratio)	40-44%	40-44%
3.	Malt extract (minimum)	80%	78%
4.	Wort viscosity (m pas/second)	<1.5	<1.5
5.	Wort turbidity	Clear	Clear
6.	Diastatic power (L.V.)	80-120	90-130
7.	Alpha amylase	Equal to or greater than check	
8.	Dimethyl sulphide (wort)	20-30ppb	20-30ppb

\*Finalized in first meeting of the N.C.G.M.B.D. at DWR, Kamal on 12 December 1995.

\*\*Revised during 43<sup>rd</sup> Annual Meeting of the All India Coordinated Wheat and Barley Improvement Project, at IARI, New Delhi (27-30 August 2004)

### BARLEY CULTIVATION IN SALINE-SODIC SOILS

Barley is relatively more tolerant to salinity/sodicity (Table 6.11). However, cultivation in saline-sodic soils requires some specific considerations to get satisfactory yield. The suitable varieties for such soils are given in the Table 6.5. The following practices are suitable for successful production of barley in saline-sodic soils.

1. Seedbed preparation is an important consideration under this situation. Efforts should

**Table 6.11** Relative tolerance of barley and some other cereals to salinity

Crop	EC of saturation extract (dS/m)	
	50 % seedling emergence	50 % yield
Barley	18	16-24
Wheat	13	14-16
Sorghum	15	13
Maize	5.9	21-24
Rice	3.6	18

Source: Mass (1986)



be made to conserve as much moisture as possible. Deep ploughing should be avoided since it permits the water to stay for a longer period of time due to impeded percolation. Two harrowing followed by one ploughing by a cultivator provides a good tilth for barley sowing in these soils. The use of heavy ploughing machines should be avoided since it results in soil compaction which, in turn, hampers root growth and development.

2. Barley seed germination is generally not a problem, however, mortality of seedlings is high. Therefore, a higher seed rate of 100-120 kg/ha has been recommended in these situations.
3. Seeds should be placed at a depth of 4-5 cm.
4. Nitrogen in these soils should be applied in three equal splits at sowing, first irrigation and flowering (after the second irrigation). If the barley crop in these soils shows a deficiency of phosphorus and or potassium, then 30 kg of  $P_2O_5$  and or 20 kg of  $K_2O$  kg/ha should be applied once in two to three years.
5. Two to three light irrigations are sufficient. However, the exact number of irrigations should be adjusted depending on the quantity and frequency of winter rains. The critical stages for irrigation are active tillering (30 to 35 DAS), caring (60 to 65 DAS) and flowering (80 to 85 DAS). Light irrigations in saline-sodic soils are preferred because of poor percolation of water. Heavy irrigation leads to waterlogging which causes wilting of barley plants under these conditions.

#### SUMMARY

- Barley is the second major winter cereal after wheat with an world acreage of 47.54 million ha.
- Barley grains are highly nutritious with about 10% protein, 64% carbohydrates, vitamins, minerals and fibre.
- Being one of the oldest crops, it is cultivated in many continents.
- Barley is grown for diverse uses ranging from human consumption and source of livestock feed to malting and brewing industry.
- It is a hardy crop and tolerant to alkali soils, frost and drought conditions, it is preferred in many areas less suitable for other crops.
- It is cultivated in India mainly in Northern and Eastern states.
- It is distinguished from other cereals by the absence of auricles on the leaf.
- There are three types of barley on the basis of number of florets, viz. six-row barley, two-row barley and irregular barley.
- On the basis of presence or absence of lemma and palea on the seed, they are grouped into hulled or hull-less (naked) barley types.
- The barley exhibits 6 distinct growth stages, viz. germination and seedling, tillering, jointing, heading, ripening and maturity and drying stages.
- Varieties suitable for different agro-climatic conditions are available for cultivation.
- Varieties have been identified for special purposes like malting and brewing, fodder and forage, tolerant to problematic soils in different zones with vastly improved yielding potential.



- Although it can be grown on variety of soils, well-drained loamy soils with a pH range of 7-8 and medium fertility are highly suitable for its cultivation.
- The high-yielding dwarf and semi-dwarf varieties of barley respond to application of 10-15 tonnes/ha FYM and 30-80 kg N, 20-30 kg P<sub>2</sub>O<sub>5</sub> and 30 kg K<sub>2</sub>O, depending on the initial soil-fertility status.
- Application of N in three splits, viz. one-third at sowing, one-third at first irrigation and last one-third at flowering, results in better nitrogen-use efficiency.
- The time of sowing, seed rate, row spacing, depth and method of sowing differs for rainfed, irrigated, timely sown and late-sown crops.
- The irrigated crop needs irrigation at critical stages like active tillering, booting/flag leaf stage and milking/grain-filling stage. The depth of irrigation and frequency of irrigation also depends on type of barley grown.
- Barley is infested with many seasonal weeds and they cause extensive reduction in yield. Application of isoproturon @ 1.0-1.5 kg/ha or metsulfuron @ 4 g/ha as post-emergence spray at 30-35 DAS controls the weeds effectively.
- Barley is prone to many insect-pests like termites and aphids; and diseases like rusts, smuts, leaf spots, mildews, foot rot etc. Application of insecticides and fungicides at appropriate dosage at appropriate time is necessary to overcome the yield losses due to these pests and diseases.
- The crop is ready for harvest when plants turn yellow and start drying and moisture content comes to around 18-20%. The duration of crop depends on variety and cultural practices. High-yielding varieties grown with optimum agronomic practices and plant protection measures yield about 4-5 tonnes/ha grain.
- The barley is grown in many cropping systems, viz. in sequence with other cereals, legumes and other crops in *kharif* and mixed/intercropping in *rabi* with crops like peas, chickpea, mustard and rapeseed etc.

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## Small Millets

Arun Gupta and H.S. Gupta

Small millets as a group include six small-seeded crops, viz. finger millet [*Eleusine coracana* (L.) Gaertn.], foxtail millet [*Setaria italica* (L.) Beauv.], proso millet [*Panicum miliaceum* L.], kodo millet [*Paspalum scrobiculatum* L.], little millet (*Panicum sumatrense* Roth ex. roem. & Schult.) and barnyard millet (*Echinochloa frumentacea* Link) (Table 7.1). They are cultivated mainly as a rainfed crop in an area of about 2.29 million ha in India; the largest area (1.6 million ha) being under finger millet. The small millets are not important in terms of country's total foodgrain production, as they account for only 1% of it. However, they are especially valued for filling specific niches because they often succeed under stressful situations, where other crops fail to produce an acceptable harvest. They are known for their resilience by adjusting to diverse ecological situations (Seetharam, 1998). Probably no other crop can withstand drought as efficiently as small millets. Small millets are well suited to diverse agro-climatic conditions of soil, temperature and altitudes. This is reflected by their cultivation extending from sea-level in the south to high hills (up to 2,000 m amsl) in Uttarakhand and North-eastern hills. These crops are generally cultivated where few options exist for crop diversification.

Each individual millet species possesses some unique character(s) for adaptation to adverse conditions like tolerance or resistance to drought, high temperature, low soil fertility and infestation by stored grain pests (Table 7.1).

**Table 7.1** Special characteristics of small millets

Millet	Common name	Special characteristics
Finger millet	Ragi, <i>Mandua</i> , <i>Nachni</i> , <i>Kapai</i> , <i>Nagli</i> , <i>Marua</i>	Wider adaptability, rich source of calcium (Seetharam, 1998)
Foxtail millet	<i>Kauni</i> , <i>Kangni</i> , <i>Korra</i> , <i>Tenai</i> , <i>Rala</i>	Short duration, tolerant to low soil fertility and drought (Jijau, 1989)
Kodo millet	<i>Kodo</i> , <i>Varagu</i> , <i>Haraka</i> , <i>Arikalu</i>	Long duration, grown well in shallow and deep soil (Hegde and Gowda, 1989)
Little millet	<i>Kutki</i> , <i>Samai</i> , <i>Samalu</i> , <i>Same</i>	Short duration, withstand both drought and waterlogging (Doggett, 1989)
Proso millet	<i>Cheena</i> , <i>Panivaragu</i> , <i>Variga</i> , <i>Baragu</i>	Short duration, tolerant to heat and drought (Sahib, 1997)
Barnyard millet	<i>Sawan</i> , <i>Jhingora</i> , <i>Kudraivali</i> , <i>Oodalu</i>	Fastest growing, voluminous fodder (Gupta et al., 2009)





Finger millet



Foxtail millet



Kodo millet



Little millet



Proso millet



Barnyard millet

### AREA, PRODUCTION AND PRODUCTIVITY

Area under small millets has been continuously declining, with a decline of more than 72.7% from 7.7 million ha in 1949-50 to 2.10 million ha in 2009-10 (Table 7.2). However, there has been a significant improvement in the productivity of finger millet (0.7 tonne/ha to 1.49 tonnes/ha) during this period because of development of high-yielding varieties. The productivity of other small millets is less than 1 tonne/ha (Padulosi *et al.*, 2009). The situation is quite dismal in kodo and little millet (Seetharam, 1998). The frontline demonstrations conducted in various states of the country have proven that per hectare yield in all the small millets could be convincingly pushed by adopting improved production technology.

### FINGER MILLET

Finger millet is believed to have originated in African highlands of Uganda and Ethiopia (Seetharam, 1997) around 3,000 years BC and spread to India



Table 7.2 Area, production and productivity of small millets in India

Millet	Area (million ha)			Production (million tonnes)			Productivity (tonnes/ha)	
	1949- 50*	2009- 10	Difference	1949 -50*	2009 -10	Difference	1949- 50*	2009- 10
Finger millet	2.3	1.27	-0.92	1.6	1.89	0.43	0.7	1.49
Other small millets (Foxtail, Kodo, Little, Proso and Barnyard)	5.4	0.83	-4.5	2.3	0.32	-1.86	0.45	0.48
Total	7.7	2.10	-5.42	3.9	2.21	-1.43		

\*Source: Seetharam (1998); ©Source: FAI, (2011)

around 3,000 year ago. India is considered as a secondary centre of genetic diversity. Studies indicated that finger millet originated from its nearest wild relative *Eleusine africana* through selection and domestication (Gowda, 1997).

Finger millet is the most important small millet in the tropics (12% of global millet area) (ICRISAT, 2011) and cultivated in more than 25 countries in Africa (eastern and southern) and Asia (from near east to far east). Among small millets, it ranks first in India in importance. Its cultivation is more widespread than other small millets. *Mudde* (dumplings), *roti* (unleavened pan cakes) and *ambali* (porridge) are the common items made from the finger millet grains.

Compared to rice, finger millet grains are more nutritious and provide eight times more calcium, four times more minerals and two times more phosphorus per unit of grain consumed. Protein content of finger millet is more than that of rice and has a well-balanced amino acid profile. It is a good source of methionine and lysine and is also rich in important vitamins such as thiamine, riboflavin, folic acid and niacin. Lower incidence of cardio-vascular diseases, duodenal ulcers and diabetes among population consuming millets make them ideal health foods (MSSRF, 2002).

### AREA, PRODUCTION AND PRODUCTIVITY

Finger millet is widely cultivated in Tropical Africa (Ethiopia, Eritrea, Mozambique, Zimbabwe and Namibia), West Africa (Senegal, Niger and Nigeria), Madagascar, Malaysia, China and Japan. Finger millet is grown in about 1.38 million ha area in India. Karnataka has the maximum area followed by Uttarakhand, Maharashtra, Tamil Nadu, Odisha and Andhra Pradesh. These states account for 86% of the total finger millet production of the country (Table 7.3).

### VARIETAL DEVELOPMENT

A large number of varieties have been bred and released for large-scale cultivation in different parts of the country (Table 7.4).

**Table 7.3** Area, production and productivity of finger millet in different states (2009-10)

State	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
Karnataka	765.0	1,312.0	1,715
Uttarakhand	132.0	163.0	1,235
Maharashtra	120.0	109.0	908
Tamil Nadu	82.3	162.6	1,976
Odisha	59.0	37.7	639
Andhra Pradesh	45.0	53.0	1,178
Gujarat	14.0	11.0	786
West Bengal	11.8	13.9	1,180
Jharkhand	10.4	5.7	548
Bihar	10.4	8.4	808
India	1,268.0	1,888.5	1,489

Source: FAI (2011)

**Table 7.4** Released varieties of finger millet during last 12 years

Variety	Year	Areas of adaptation	Special features
GPU 28	1998	Karnataka	High yield and blast resistance
OUAT 2 (Shubra)	1998	Odisha	White seeds and high protein
Maruthi (PR 23)	1999	Andhra Pradesh	Early and high yielding
BM 9-1	1999	Karnataka, Andhra Pradesh, Odisha, Madhya Pradesh and Maharashtra	High yielder, moderately resistant to blast and brown spot
GPU 26	2000	Karnataka	Early and blast tolerant
GPU 45	2001	Madhya Pradesh, Gujarat, Jharkhand, Karnataka and Maharashtra	Early, blast resistant and high grain yield
Chilika (OEB 10)	2001	Odisha, Madhya Pradesh, Gujarat, Andhra Pradesh and Tamil Nadu	Moderately resistant to blast, resistant to stem borer
VL 315	2004	Uttarakhand	Medium duration, tolerant to finger and neck blast
TNAU 946	2004	Tamil Nadu	Medium duration
Co (RA) 14	2005	Tamil Nadu	Medium duration
VL 324	2006	Uttarakhand	Early duration, tolerant to finger and neck blast
VR 762 (Bharathi)	2007	Andhra Pradesh	Medium duration, suitable for both <i>rabi</i> and <i>kharif</i> cultivation
MR 6 (Divya)	2008	Karnataka	Medium duration, tolerant to neck and finger blast
ML 365	2009	Karnataka	Drought tolerant
PRM 1	2009	Uttarakhand	Dual purpose (yield + fodder)

Table 7.4. *contd*



Table 7.4 concluded

Variety	Year	Areas of adaptation	Special features
GPU 48	2010	Karnataka	Short duration
VR 847 (Chaitanya)	2010	Andhra Pradesh	Medium duration
GPU 67	2010	Chhattisgarh, Jharkhand, Karnataka, Maharashtra, Tamil Nadu	Late duration

### THE PLANT

Finger millet is a 50-150 cm tall robust tufted annual plant with a good tillering ability. The stem is erect or slightly kneeed. The leaves are linear and distichous. The leaf sheaths are compressed, open and glabrous with more or less ciliate margins. The leaf sheath more or less envelops the entire stem and only small parts of internodes are exposed. Internodes are not of equal length and are very short at the base (Sundararaj and Thulasidas, 1976).

There are four recognized types of earhead shapes in finger millet: (i) top curved (fingers curve at top), (ii) incurved (practically closed), (iii) fist shaped (completely incurved), and (iv) open (short open or long open). The inflorescence is a terminal umbel. Finger millet inflorescence is the whorl of 2-11 spikes. The spikes are 8-15 cm long and 1.3 cm wide. In each spike, about 50-70 spikelets are arranged alternatively on one side of the rachis (Gupta *et al.*, 2010). Each spikelet contains 3-13 florets. Finger millet is highly self-pollinated and natural out-crossing does not exceed 1%. On the basis of ear head shape and plant morphology, finger millet is divided into four botanical races namely *elongata*, *plana*, *compacta* and *vulgaris* (De Wet, 1989). Finger millet is a C<sub>4</sub> plant.

### CLIMATE

Finger millet has a wide range of seasonal adaptation and is grown in varying soil and temperature conditions. It can be grown throughout the year if the temperature is above 20°C. Finger millet being a tropical crop experiences both temperature and moisture stress (Udayakumar *et al.*, 1997) but the crop has good drought-recovery characteristics. The crop is grown in the areas where rainfall ranges from 550 to 1,250 mm or more.

### SOIL

Finger millet is well adapted to different kinds of soil. It is well suited to alluvial, sandy and loamy soil; and withstands certain degree of alkalinity and acidity in soil. It can be grown in heavy and black soils provided they are well drained.

### SEEDBED AND SOWING

#### Seedbed

Finger millet is predominantly a rainfed crop, therefore two ploughings are recommended for moisture conservation. The first ploughing should be deep

and done when the pre-monsoon showers occur. The second ploughing is light and done at the onset of monsoon.

### Sowing

*Time of sowing:* *Kharif* crop is generally sown in June in most parts of the country. Finger millet is also sown as a *rabi* (winter season) crop or a spring-summer irrigated crop in some parts of the country. The optimum sowing time in various states and agro-ecosystem is given Table 7.5.

**Table 7.5** Recommended sowing time, spacing and fertilizer dose for finger millet in various states

State	Optimum sowing time	Spacing (cm × cm)	Fertilizer N:P:K (kg/ha)
<b>Rainfed</b>			
Andhra Pradesh	June to July	22.5 × 15	40:20:20
Summer irrigated	January-February	22.5 × 7.5	90:30:20
Bihar	June	22.5 × 10	40:20:20
Gujarat	June	30 × 7.5	80:40:0
Chhattisgarh	June	22.5 × 7.5	40:40:0
Jharkhand	June	22.5 × 10	40:20:20
Karnataka	June to July	22.5 × 10	50:40:25
Summer irrigated	January-February	22.5 × 10	100:50:50
Maharashtra	June	22.5 × 10	25:20:0
Madhya Pradesh	June	22.5 × 7.5	40:40:0
Odisha	June	22.5 × 10	40:20:20
Irrigated	June	22.5 × 5	60:20:20
Tamil Nadu	June	22.5 × 15	60:30:30
Summer irrigated	January-February	22.5 × 15	90:45:45
Uttarakhand	June	22.5 × 10	40:20:0

*Source:* Seetharam *et al.* (2001).

*Method of sowing:* Finger millet is mostly sown broadcast but sowing in rows gives higher grain yield (Prakash *et al.*, 2008). Sowing in rows is also beneficial for intercultural operation and control of weeds. It can also be transplanted if a nursery has been raised. Transplanting of 2 seedling/hill with the onset of monsoon is the best practice for obtaining optimum yield. Seedlings (at 5 leaves stage) are thinned or transplanted to fill the gap in the field for maintaining optimum plant population of 4 to 5 lakh plants/ha.

*Seed rate and spacing:* About 6-8 kg seeds/ha is required for sowing in rows, whereas 4-5 kg seed/ha is required for transplanting. Sowing in rows 22.5 cm apart results in higher crop yield as compared to closer (15 cm) or wider (30 cm) row spacing (Pradhan, 1994). However, different row spacings have been recommended for different states (Table 7.5).

### Manuring and fertilization

Finger millet responds well to nitrogen and phosphorous fertilizers. Recommended dose of fertilizer vary from state to state (Table 7.5).



The efficiency of the recommended nitrogen can be enhanced by split application, i.e. half as a basal dose and the rest at late tillering stage (Prakash *et al.*, 2008). Application of magnesium (50 kg/ha) and calcium (16.8 kg/ha) benefits the crop (Nathan, 1995). Application of 75% recommended level of N+ farmyard manure @ 5 tonnes/ha + *Azospirillum* inoculation gave higher yield than to 100% N applied in the form of inorganic fertilizer (Arunachalam *et al.*, 1995). Use of biofertilizer as seed inoculant particularly phosphorus-solubilizing *Azospirillum* + *Aspergillus awamori* @ 25 g/kg is beneficial in finger millet production (Nigade *et al.*, 2007).

### WEED MANAGEMENT

Weeds are a major problem in finger millet cultivation; the first 45 days after germination being critical. Therefore, 2-3 weedings are required either by manual or animal drawn weeder. Application of 2, 4-D @ 1.0 kg active ingredient/ha as post-emergence was found effective for controlling broad-leaved weeds. Pre-emergence application of isoproturon @ 0.75 kg/ha can effectively control the weeds in finger millet during initial growth stage.

### CROPPING SYSTEMS

Finger millet is generally intercropped with pulses and oilseeds. In Karnataka, Tamil Nadu, Andhra Pradesh and Odisha finger millet-pigeonpea combination in 8:2 row proportion gave higher monetary return (Gowda *et al.*, 2004). In hills of Uttarakhand finger millet and soybean in alternate rows at spacing of 37.5 cm gave 5,690 kg/ha finger millet equivalent grain yield (Prakash *et al.*, 2008). At Jagdalpur (Madhya Pradesh), intercropping finger millet with sesame, soybean, blackgram, horsegram or pigeonpea increased production and net returns (Table 7.6) (Pradhan and Thakur, 2012). Among the finger millet-based sequential cropping systems, those involving a legume are helpful in sustaining higher yield in the long run.

**Table 7.6** Grain yield and net returns from sole and intercropped finger millet at Jagdalpur (Madhya Pradesh) (data averaged over 2 years)

Cropping system	Grain yield (q/ha)		Net return (₹/ha)
	FM	Intercrop	
Finger millet (sole crop) (FM)	14.6	—	9,304
FM + sesame (4:1)	14.4	3.4	27,359
FM + soybean (4:1)	12.2	7.8	21,240
FM + blackgram (4:1)	14.1	7.9	35,856
FM + horsegram (4:1)	13.0	6.0	21,967
FM + pigeonpea (4:1)	14.2	9.2	49,537

Source: Pradhan and Thakur (2012)

### DISEASES AND THEIR CONTROL

Blast, leaf blight, wilt and cercospora leaf spot are the major diseases of finger millet.



**Blast**

Blast (*Pyricularia grisea*) is the most serious disease of finger millet. A temperature of 25-30°C, humidity of 90% and cloudy days with intermittent rains are optimum for disease development (Viswanath *et al.*, 1997). The disease occurs at all the stages of plant growth. The pathogen attacks the leaf, finger and neck. Finger infection usually starts from apical portion and spreads to base. In neck-infected portion immediately below the earhead turns initially brown and later on black due to fungal infection and results in ear drop. An olive grey growth of the fungus can be observed in the infected area. The extent of damage and yield reduction depends on time of infection and weather parameters. Trivedi (2001) suggested the use of resistant varieties, seed treatment with thiram or mancozeb (2g/kg seed) and reduction of nitrogenous fertilizer by 25% reduces the blast intensity. Need-based (2-3) sprays of ediphenphos (0.1%) or carbendazim (0.05%) or Saff (0.2%) have been found effective in controlling blast (Bhatt and Pant, 1997; Ramappa *et al.*, 2002).

**Leaf blight**

Leaf blight (*Helminthosporium nodulosum*) causes major damage at the seedling stage. If infected seeds are used for sowing, then seeds may not germinate at all due to pre-emergence rot, if germinated then post-emergence rot is observed. The disease is more, when the temperature ranges between 30 and 32°C coupled with high humidity (McRae, 1932). Treating seed with either tricyclazole (2 g/kg seed) or need based spray of mancozeb (0.2%) at tillering stage reduces the disease incidence.

**Wilt or foot rot**

Symptoms of foot rot (*Sclerotium rolfsii*) start from the base of the stem, which initially appears water soaked and later turns brown and dark brown with concomitant shrinking of the stem in the affected region. White fan like mycelial growth can be observed at the basal region. Later on mustard seed like sclerotia are formed. Since fungus is mainly soil-borne, chemical control is not feasible. Foot rot can be managed by adopting proper crop rotation with non-graminaceous crops.

**Leaf spot**

It is a serious disease of finger millet in hilly areas, where rainfall is high and mean daily temperature does not exceed 20°C. The leaf spot (*Cercospora* spp.) disease begins as spots on the lower leaves and severe infection causes drying out of leaves.

**Viral diseases**

Two viral diseases, namely mottle streak virus and streak virus, are prevalent on finger millet in Karnataka, Tamil Nadu and Andhra Pradesh. The yield loss caused by streak viruses can be minimized by spraying dimethioate 30% EC (0.05%) or phosphamidon (0.05%) or methyl demeton (0.05%) 20-30 days after sowing.



## INSECT-PESTS AND THEIR CONTROL

The problem of insect-pests in finger millet is negligible. Some incidence of following insect-pests has been reported from finger millet in recent years.

### Pink stem-borer

Pink stem-borer (*Sesamia inferens*) is reported from all the finger millet-growing states mainly from Odisha, Karnataka, Tamil Nadu and Andhra Pradesh. Moth lays eggs between stem and leaf sheath. After incubation, young larvae bore into stem and cause dead heart that results in either partial or complete chaffy ear head. Spraying of imidacloprid @ 0.3 ml/litre or monocrotophos @ 1.25 ml/litre has been found effective in controlling stem-borer (Prakash *et al.*, 2008).

### Cut worm

Cut worms (*Spodoptera exigua*) causes damage in finger millet nurseries and cut seedling at the base. To control cut worm dusting with malathion 5% or phosaline 4% or quinolphos 1.5% @ 24 kg/ha or endosulfan 4% @ 12 kg/ha can be undertaken to control cut worm (Mohapatra, 1997).

## HARVESTING AND THRESHING

Harvesting is generally done in two stages. With the help of sickle, first the ear-heads are cut and then the stem is cut close to the ground. Threshing of finger millet is cumbersome and labour intensive. Traditionally threshing is done by beating the ear-heads with sticks to separate grains. To overcome this problem, The Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora has developed finger millet thresher 'Vivek Millet Thresher 1', which can thresh 35-40 kg earhead in one hour (Gupta *et al.*, 2006). After threshing grains are sun dried for 3-4 days and then stored.

## OTHER SMALL MILLETS

Other small millets support diversified agriculture system in the country especially hilly and tribal areas. They are cultivated in all the states in patches. Foxtail millet ranks first among the small millets produced globally with China being the main producer (3.7 million tonnes) (Lin, 2005). It is mainly grown on poor or marginal soils in southern Europe and in temperate, subtropical, and tropical Asia (Marathe, 1993). Eastern Asia is considered to be centre of origin of foxtail millet. Andhra Pradesh and Karnataka are the major foxtail millet-growing states in India. These two states account for 55% of the total area under foxtail in the country.

India and West Africa are the major growers of kodo millet. It was domesticated in India about 3,000 years ago and India is considered as the centre of origin of this crop (Yadava, 1997). Among small millets, it has the maximum planted area after finger millet in India. It is grown for food and feed in the tribal belt of Madhya Pradesh, Chhattisgarh and Andhra Pradesh.

Little millet is also considered of Indian origin. *Panicum psilopodium* is considered as a progenitor of little millet (Haider, 1997). It is grown in patches

in Karnataka, Andhra Pradesh, Tamil Nadu, Odisha, Bihar, Maharashtra and Madhya Pradesh.

Proso millet is widely cultivated in India, Nepal, West Burma, Sri Lanka, Pakistan and other South-East-Asian countries. It is a native of Egypt and Arabia and has been cultivated in Asia minor and southern Europe since pre-historic times (Matz, 1986). It is sparsely cultivated in Bihar, Maharashtra, Rajasthan, Andhra Pradesh, Gujarat, Odisha, Tamil Nadu and Jammu and Kashmir.

Barnyard millet is grown in India, Japan and China as a substitute for rice under natural precipitation. In India, it is generally grown in Uttarakhand, where it occupies nearly 72,000 ha area. It is also grown in other hilly states, viz. Arunachal Pradesh, Asom, Jammu and Kashmir, Meghalaya, Nagaland, and Himachal Pradesh in patches.

The area, production and productivity of small millets other than finger millet in different states of India are given in Table 7.7.

**Table 7.7** Total area, production and productivity of small millets other than finger millet in different states (2008)

State	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
Madhya Pradesh	268.4	73.5	274
Chhattisgarh	153.4	28.0	183
Uttarakhand	72	70	972
Maharashtra	59	23	390
Gujarat	58	57	983
Karnataka	27	11	407
Tamil Nadu	33.1	31.1	940
Andhra Pradesh	25	13	520
Jharkhand	24.9	11.9	478
Arunachal Pradesh	21.4	18.4	860
Odisha	17.8	10.1	567
Bihar	4.0	3.0	750
India	830.5	381.9	460

Source: FAI (2011)

## CLIMATE

All the small millets are well adapted to varied tropical conditions but proso millet and barnyard millet can be grown in higher elevations.



moisture-holding capacity. Proso millet grows well on most soils except the coarse sandy soil. Little millet and barnyard millet are grown in marginal lands having shallow soil and low moisture-holding capacity.

### IMPROVED VARIETIES

A number of high-yielding varieties in all the small millets have been developed and released by various research institutes and universities for different states. The details are given in Table 7.8.

**Table 7.8** Improved varieties of small millets (other than finger millet)

Variety	Year	Areas of adaptation	Special features
<i>Foxtail millet</i>			
PS 4	1998	All States	Wide adaptation and high yield
TNAU 43	1998	Tamil Nadu, Andhra Pradesh and Karnataka	-
SR 16 (Meera)	2000	Rajasthan	Stay green character
Sri Lakshmi	2002	Andhra Pradesh	-
SR 51	2003	Rajasthan	Bold seeds
PRK 1	2000	Uttar Pradesh	-
Co (TE) 7	2006	Tamil Nadu	Tolerant to rust, bold seed
<i>Kodo millet</i>			
Vambal 1	1996	Tamil Nadu	-
(RMV 20)	2000	Madhya Pradesh and Karnataka	Resistant to head smut and shoot fly
RBK 155			
Jawahar Kodo 48	2001	Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Karnataka and Gujarat	Tolerant to head smut and high grain yield
KK 2	2002	Uttar Pradesh	Resistant to drought, lodging and suitable for saline condition
Jawahar Kodo 439	2005	Madhya Pradesh	-
Jawahar Kodo 13	2007	Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Andhra Pradesh, Tamil Nadu, Karnataka	Medium tall, non-lodging
Jawahar Kodo 65	2009	All kodo millet-growing states	Moderately resistant to head smut and shoot fly
<i>Little millet</i>			
CO 6 (TNAU 63)	1997	Tamil Nadu, Gujarat and Karnataka	High seed yield
Paiyur 2	2000	Tamil Nadu	-
OLM 203	2001	Karnataka, Odisha,	-

Table 7.8 contd

Table 7.8 *concluded*

Variety	Year	Areas of adaptation	Special features
		Andhra Pradesh, Bihar and Tamil Nadu	
OLM 36	2001	Madhya Pradesh, Odisha, Chhattisgarh, Bihar, Karnataka and Gujarat	Early maturity and high seed yield
OLM 20	2003	Odisha, Madhya Pradesh and Chhattisgarh	Suitable for rainfed upland condition
Co (Samai) 4	2007	Dryland of Tamil Nadu	Moderately resistant to shoot fly
OLM 208	2009	Odisha, Chhattisgarh and Gujarat	Long compact panicle and moderately resistant to shootfly
<i>Proso millet</i>			
GPUP 8	2001	Karnataka	Resistant to brown spot
GPUP 21	2003	Karnataka and Tamil Nadu	Suitable for late sowing
Pratap Cheena 1	2006	Rajasthan	Extra early variety
TNAU 145	2009	Tamil Nadu and Karnataka	Profuse tillering and non-lodging
TNAU 164	2010	Andhra Pradesh, Bihar, Karnataka, Maharashtra, Tamil Nadu	Long panicle and high yielding
TNAU 151	2010	All proso millet growing states	-
PRC 1	2010	Uttarakhand hills	-
<i>Barnyard millet</i>			
Sushrutha (RAU 11)	2000	Karnataka	-
VL Madira 172	2000	Uttar Pradesh, Gujarat and Karnataka	Tolerant to grain smut
VL Madira 181	2001	Bihar, Karnataka, Madhya Pradesh and Tamil Nadu	High grain yield
Pratap Sanwa 1	2006	Rajasthan	Tolerant to smut and shoot fly
VL Madira 207	2008	All barnyard millet-growing states except Tamil Nadu and Gujarat	Tolerant to grain smut
PRJ 1	2009	Uttarakhand hills	Small awn in spike. Stiff straw, Immune to grain smut



## THE PLANT TYPE OF SMALL MILLETS

### Foxtail millet

Foxtail millet is an annual, growing to a height of 1-1.5 m. Culms are erect, slender with hollow internodes and tillers develop from the basal buds. Leaf sheath is longer than internodes, glabrous or slightly hairy with short ligule. The inflorescence is a spike up to 30 cm long (Gowda *et al.*, 2002). Spikelets are two flowered protected by two glumes and are generally in cluster of 40-50. Each spikelet is subtended by 1- 4 bristles.

### Kodo millet

Kodo millet is an annual having erect culm (sometime trailing) and showed profuse tillering. Spikes are 2-6 in number and 3-15 cm long (Sundararaj and Thulasidas, 1976). Spikelet are usually sessile or with short pedicilate on a flattened rachis. The spikelets are arranged in two or more regular or irregular long and short combinations (Nanda and Agrawal, 2008).

### Little millet

It is an annual with a height of 0.75 to 1 m, slender stem, leaves linear 20-40 cm long and 0.5-0.6 cm wide, leaf sheath often glabrous with hair at junction (Nanada and Agrawal, 2008). Panicle is 15-40 cm long with spikelet mostly bearing on unequal pedicels and solitary at the end of branches (Seetharam *et al.*, 2003). The grain is enclosed within lemma.

### Proso millet

Proso millet is an erect annual 30-100 cm tall, with tillers and adventitious root system (Baltensperger, 2002). Proso millet inflorescence is a drooping panicle that may be open or compact (Hulse *et al.*, 1980), primary branches spreading or ascending or appressed, terminating in a spikelet. The spikelet is generally solitary and about 0.5 cm long.

### Barnyard millet

It is an erect plant growing to a height of 250 cm. Inflorescence is usually erect rarely drooping. Racemes are few to numerous, densely crowded with spikelets arranged in 4 irregular rows on the triquetrous rachis. Spikelets are two flowered, awnless and placed on short rough pedicels subtended by two glumes. The upper floret is bisexual, while lower floret is sterile. Grain is 2-3 mm long and 1-2 mm wide and enclosed in a white shining hardened lemma and palea. It is highly self-pollinated species (Gupta *et al.*, 2010).

### Seedbed preparation and sowing

**Seedbed:** The field should be ploughed to get good tilth for conserving soil moisture followed by planking with the onset of moisture. The field should be leveled properly and drainage facilities to be provided in the high rainfall areas.

**Time of sowing:** The small millets are normally sown with the onset of monsoon. The sowing time varies from state to state and millet to millet. The

optimum sowing time for different small millets in various states is given in Table 7.9.

**Table 7.9** Optimum sowing time of small millets in various states

State	Foxtail millet	Kodo millet	Little millet	Proso millet	Barnyard millet
Tamil Nadu	August-September	-	June (south-west monsoon) and September (north-east monsoon)	Sep.-Oct.	September-October February-March
• Irrigated	June-July				
• Summer	January				
• irrigated					
Karnataka	July-August		Last week of June-1st week of July	July	
Andhra Pradesh	1st fortnight July			July and September-October*	
Maharashtra	2nd fortnight July				
Uttar Pradesh	Middle of June	June-July		March to May <sup>o</sup>	
Bihar/Jharkhand	Middle of June		Last week of June-1st week of July	March to May <sup>o</sup>	
Uttarakhand	May-June			May-June	May-June
Odisha			Middle of June		
Madhya Pradesh and Chhattisgarh		June-July	Last week of June-1st week of July		

\*Late *kharif* crop or rabi crop; <sup>o</sup> Irrigated catch crop

**Spacing and seed rate:** These crops are usually sown by broadcasting either as a sole crop or mixed with other crops. However sowing in rows is better. The recommended spacing and seed rate is given in Table 7.10.

**Manuring and fertilization:** Addition of farmyard manure or compost @ 5 tonnes/ha improves water-holding capacity and soil health. It can be supplemented with chemical fertilizer. The small millets respond well to

**Table 7.10** Recommended spacing and seed rate in different small millets

Millet	Spacing (cm × cm)	Seed rate	
		Line sowing (kg/ha)	Broadcasting (kg/ha)
Foxtail millet	25-30 × 8-10	8-10	15
Kodo millet	22.5 × 10	10	15
Little millet	22.5 × 8-10	8	12
Proso millet	25 × 10	10	15
Barnyard millet	22.5 × 10	8	10-12



moderate application of N and  $P_2O_5$ . The response to K has not been observed. Application of 40 kg N/ha produced profitable yield in barnyard millet and proso millet, whereas 20 kg N/ha appeared optimum for foxtail, kodo and little millet (Table 7.11).

**Table 7.11** Recommended dose of fertilizer (N: $P_2O_5$ : $K_2O$ , kg/ha) for small millets (other than finger millet) in various states

State	Foxtail millet	Kodo millet	Little millet	Proso millet	Barnyard millet
Tamil Nadu	40:20:0	40:20:0	40:20:0	40:20:0	40:20:0
Karnataka	30:15:0	20:20:0	20:20:0	20:20:0	20:20:0
Maharashtra	20:20:0	20:20:0	20:20:0	20:20:0	20:20:0
Andhra Pradesh	40:30:0	20:20:0	20:20:20	20:20:20	20:20:20
Uttar Pradesh		20:20:0		40:20:0	40:20:0
Bihar	20:20:0		20:10:0	40:20:0	40:20:0
Uttarakhand	20:20:0			20:20:0	40:20:0
Odisha		40:20:0			
Madhya Pradesh		40:20:0			
Chhattisgarh	20:20:0			20:20:0	

Source : Seetharam *et al.* (2001)

Results of frontline demonstrations showed that application of recommended dose of fertilizers would enhance the yield substantially to a tune of 59% in kodo millet, 62% in little millet and 108% in barnyard millet (Table 7.12).

**Weed management:** The critical period for crop-weed competition is initial 45 days in all the small millets. Two manual weedings at 15-20 days and 30-35 days after sowing are sufficient to control the weeds. Isoproturon @ 0.5-0.75 kg a.i./ha applied as pre-emergence spray or mixed with sand/soil along with 1 hand-weeding 30-45 days after sowing has been found effective in controlling weeds and gives higher yield in kodo, foxtail and barnyard millet (AICSMIP, 2002; AICSMIP, 2005).

**Intercropping:** Intercropping foxtail millet and pulses (greengram/cowpea/field bean) in 4:2 row proportions has been found to be ideal for enhancing yield

**Table 7.12** Effect of application of recommended dose of fertilizer on grain and straw yield (kg/ha)

Crop	State	Recommended fertilizer dose		Farmers practice		Increase over farmers practice %	
		Grain	Straw	Grain	Straw	Grain	Straw
Kodo millet	Madhya Pradesh	1,456	3,735	913	1,808	59	106
Little millet	Madhya Pradesh	1,253	3,120	772	1,720	62	81
Barnyard millet	Uttarakhand	1,758	6,344	844	3,908	108	62

Source : Seetharam *et al.* (2001)

of both foxtail millet and pulse crops (AICSMIP, 2002). Intercropping of kodo millet and pigeonpea in 8:2 row proportion recorded yield advantage of 173% over farmers practice (Table 7.13).

**Table 7.13** Kodo millet grain equivalent yield (KMGEY), net returns and benefit : cost (B:C) ratio as influenced by inter cropping kodo millet and pigeonpea

Treatment	Grain yield (kg/ha)			increase over, farmers' practice %	Gross return (₹/ha)	Cost of culti. (₹/ha)	Net return (₹/ha)	B:C ratio
	Kodo millet	Pigeon pea	KMGEY					
Farmers' practice (broadcasting)	334	47	475	-	2,375	3,200	-825	0:75
Recommended practice 2:1	551	206	1,169	146	5,845	3,880	1,965	1:51
Advance practice 8:2	869	142	1,295	173	6,475	4,150	2,325	1:56

Source : AICSMIP (2002)

In Chhattisgarh, an intercropping of kodo millet and soybean in 4:1 row proportion (AICSMIP, 2007) gave significantly higher kodo millet equivalent grain yield (5,897 kg/ha) followed by kodo millet–pigeonpea intercropping (4,217 kg/ha).

Intercropping of little millet and soybean in 2:1 proportion gave higher little millet grain equivalent yield (LMGEY) and net monetary return in Madhya Pradesh and pigeonpea intercropping in 8:2 row proportion recorded the maximum LMGEY in Karnataka and Jharkhand (AICSMIP, 2005).

Intercropping of barnyard millet and soybean under rainfed conditions in 1:3 and 1:1 ration was found to be the best, giving highest total production in terms of barnyard millet equivalent yield of 4,430 kg/ha and 3,760 kg/ha respectively.

### DISEASES AND THEIR CONTROL

**Blast of foxtail millet:** The severity of blast (*Pyricularia setariae*) disease depends on the climatic factors such as rainfall, temperature and humidity. Spray of mancozeb (0.2%) has been found effective if the diseases appeared at the early growth stage.

**Rust of foxtail millet:** The rust (*Uromyces setariae-italica*) affects the crops at all the stages of growth. Numerous pustule appear on the both sides of the leaf. They are full of powdery mass. At the beginning, pustules are generally brown but later on they turn black. Foliar spray of wettable sulphur (0.3%) or mancozeb reduces the disease intensity.

**Downy mildew or green ear disease of foxtail millet:** Green ear disease (*Sclerospora graminicola*) causes yield losses up to 50% (Viswanath and Seetharam, 1989). Floral bract (glume lemma, palea) turned into leaf like appendage of variable size giving green ear like appearance. Seed treatment with ridomil MZ 72 wp or chlorothalonil (2 g/kg seed) followed by one foliar



## Small Millets

spray of mancozeb (0.2%) is effective in minimizing the disease (Prakash *et al.* 2008).

**Head smut of kodo millet:** The panicle is transformed into long sorus surrounded with a creamy membrane which bursts at maturity releasing black mass of spore. The disease causes considerable yield losses (Jain and Yadava, 1997). Treating kodo millet seed with carboxin @ 2g/kg was found effective in controlling head smut (*Sorosporium paspali*) (AICSMIP, 2008) besides producing higher grain yield and was comparable to seed treatment with carboxin 1 g + *Trichoderma viride* 2.5 g/kg (Table 7.14).

**Table 7.14** Effect of chemicals on head smut and yield of kodo millet

Treatments	2006		2007		Mean	
	Head smut	Grain yield (kg/ha)	Head smut	Grain yield (kg/ha)	Head smut	Grain yield (kg/ha)
Seed treatment with carboxin @ 2 g/kg	0.2 (0.83)	1250	0.0 (0.71)	1,630	0.1	1,440
Seed treatment with <i>T. virideae</i> @ 5 g/kg	7.2 (2.69)	1,085	5.5 (2.37)	1,500	6.35	1,293
Seed treatment with carboxin 1g + @ <i>T. viride</i> 2.5 g/kg	0.3 (0.88)	1,200	0.0 (0.71)	1,650	0.15	1,425
Seed treatment with ecomonas @ 5 g/kg	7.1 (2.74)	1,090	5.6 (2.46)	1,525	6.35	1,308
Seed treatment with tricyclazole @ 2g/kg	4.7 (2.23)	1,125	2.3 (1.55)	1,580	3.5	1,353
Seed treatment with azotobacter	9.4 (3.13)	1,100	7.9 (2.88)	1,500	8.65	1,300
Untreated control	17.9 (4.28)	980	10.9 (3.37)	1,480	14.4	1,230
SEm±		28	0.15	17		
CD (P = 0.05)	87	0.462	52			

Figures in parentheses are square-root transformed values

**Rust of little millet:** Rust (*Uromyces linearis*) is the most common disease of little millet. Numerous, narrow minute brown pustule arranged in linear rows appears on the upper surface of leaves. Seed treatment with carbendazim/carboxin/sixer @ of 2g/kg seed and one foliar spray with either carbendazim or sixer 0.05% was found effective in controlling grain smut (AICSMIP, 2006).

**Smut of proso millet :** Proso millet is relatively less affected by diseases. Some incidence of smut (*Sphacelotheca destuens*) was reported in proso millet. This can be effectively controlled by adopting proper crop rotation.

**Grain smut of barnyard millet :** The infected ovaries enlarge two to three times than normal size. Seed treatment with carbendazim @ 2 g/kg seed and its need based spray @ 0.1% during flowering stage effectively controlled the grain smut (*Ustilago panici-frumentacei*) of this crop.



### PESTS AND THEIR MANAGEMENT

*Shoot fly* : Shootfly (*Atherigona pulla*) is the major seedling pest of all the small millets and causes substantial yield reduction in proso, kodo, little and barnyard millets (Nageshchandra and Ali, 1983). At seedling stage, adult fly deposits 30-40 eggs on very tender stem. The maggot comes out from the egg in 1-2 days and gradually reaches the growing point (Jagadish *et al.*, 2008). Early sowing is the low priced method of control. Dusting of carbofuran @ 20-25 kg/ha in morning time was found effective in reducing shootfly incidence.

### HARVESTING AND THRESHING

Harvesting should be done when the earhead colour starts fading or grains at lower portion of earhead mature. Grain maturity is not uniform in proso millet. Delayed harvesting causes considerable yield losses due to shattering and bird damage. Well dried grains can be stored for a long period.

All the small millets (except finger millet) have outer tough seed-coat layer. The separation of seed coat from the endosperm is usually done by repeated pounding in the mortar. There is no well-proven industrial process available at present. However, Vivek Mandua and Madira Thresher I developed by the Vivekananda Parvatiya Krishi Anusandhan Sansthan can thresh as well as dehull (removal of seed coat) all the small millets by changing the speed of thresher.

### SUMMARY

- Small millets as a group include six small seeded crops, viz. finger millet, foxtail millet, kodo millet, little millet, proso millet and barnyard millet.
- These crops are generally cultivated where few options exist for crop diversification.
- These crops are well suited to diverse agro-climatic condition of soil, temperature and altitudes.
- During the last sixty years the area under small millets has declined more than 70% from 7.7 million ha (1951) to 2.28 million ha.
- Barring the finger millet, the productivity of other small millets is less than 1,000 kg/ha and remained stagnant around 500 kg /ha. The situation is quite dismal in kodo and little millet. In general, the productivity of small millets is lower than the major cereal crops.
- To boost the production and productivity of small millets, many high yielding varieties in all the small millets were developed and released for different agro-climatic regions of the country.
- Apart from this, agronomic practices such as sowing time and method of sowing, plant geometry, fertilizer doses and suitable cropping system as well as integrated disease management measures were evolved for achieving sustainable production.
- Demonstrations conducted at farmer's field have shown that the productivity of these crops could be significantly increased by adopting improved production technology. The chapter provides information on recently released varieties, agro-production and protection technology for different states.



## **Kharif Pulses**

**(Pigeonpea, greengram, blackgram, cowpea,  
horsegram and mothbean)**

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*I.P.S. Ahlawat and B.G. Shivakumar*

India has the distinction of having the highest area under *kharif* (rainy season) and summer pulses in the world. It ranks first in both area and production of all-important pulses grown during *kharif*, viz. pigeonpea [*Cajanus cajan* (L.) Millsp.], greengram [*Vigna radiata* (L.) Wilczek.], blackgram [*Vigna mungo* (L.) Hepper], cowpea [*Vigna unguiculata* (L.) Walp.], horsegram [*Macrotyloma uniflorum* (Lam.) Verd.] and mothbean [*Vigna aconitifolia* (Jacq.) Marechal].

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is considered to be a crop of Indian origin and diversity (Van der Maesen, 1980). It was introduced in the African continent about a 1,000 years ago where different strains developed. True wild pigeonpea has not been found anywhere. They exist mostly as remnants of cultivated species. In several places, pigeonpea persists in forest. The closest wild relative of pigeonpea *Atylosia canifolia* Haines has been found in some localities in east India. Most other *Atylosia* spp. are found scattered throughout India. A group of endemic *Atylosia* grows in North Australia. In Africa, *Cajanus kerstingii* grows in the drier belts of Senegal, Ghana, Togo and Nigeria. Pigeonpea occurs throughout tropical and subtropical regions and in the warmer temperate regions from 30° N to 30° S.

According to de Candolle (1886), Vavilov (1926) and Zuckoviskij (1962), greengram originated in the Indian sub-continent. Maximum diversity occurs among related species, which are well spread in the Himalayas extending their distribution to the north-eastern region to down south in the peninsular India. The secondary centre of diversity exists in the Indo-Gangetic plain. Like greengram, blackgram is also supposed to have originated in India. From India it spread to other countries (Purseglove, 1974).

With the availability of related wild species in the central Africa it has been considered to be the home of cowpea. The crop was possibly domesticated during the Neolithic period.

Horsegram is said to have originated in the Indian sub-continent. Mehra (2000) reported that horsegram was used as food material about 2000 BC in India. There are mentions of horsegram in the many ancient Sanskrit texts in

India. It is said to have spread to other countries, notably Myanmar, Australia, West Indies and Africa from here.

Indian sub-continent is said to be centre of origin for mothbean (Purse-glove, 1974). It is well distributed in the tropical dry environments of India, Pakistan, Myanmar and Sri Lanka. Unlike other pulse crops its distribution is not very wide. Its usage as food has been observed from a very ancient time in India. Mention is there in many of the texts dating back to 2000-2500 BC.

Due to hardy nature of these crops they find a place in almost all areas which are less favourable for the cultivation of other crops. Their productivity, however, is still far below their potential. Pulses are grown in almost all the states in India excluding some areas of Jammu and Kashmir, Himachal Pradesh and hilly north-eastern states.

### AREA, PRODUCTION AND PRODUCTIVITY

#### Pigeonpea

Pigeonpea [*Cajanus cajan* (L.) Millsp., syn. *Cajanus indicus* Spreng], also known as *arhar*, *tur*, redgram, congopea, gungopea, no eye pea etc., is one of the most important pulse crops cultivated in India. It is next only to chickpea in area and production among all the pulse crops grown in India and *numero uno* among *kharif* pulses. Its grains are highly nutritious and rich in protein (21.7%), carbohydrates, fibre and minerals.

*World:* Pigeonpea is grown world over mostly in tropical and sub-tropical countries of Asia, Africa and Caribbean island nations for grain, green manuring, fodder and forage as sole crop, intercrop, mixed crop and in sequential cropping systems (Table 8.1). Among the major countries growing pigeonpea, India ranks first with about 75% of the world area and 67% of

**Table 8.1** Area, production and productivity of pigeonpea in different countries (2010)

Continent/Country	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
<i>Asia</i>			
India	3.53	2.46	697
Myanmar	0.58	0.72	1,246
Nepal	0.02	0.02	876
<i>Africa</i>			
Malawi	0.24	0.18	775
Kenya	0.16	0.10	651
Uganda	0.09	0.09	1,011
United Republic of Tanzania	0.08	0.06	733
Democratic Republic of the Congo	0.01	0.01	582
<i>Caribbean islands</i>			
Dominican Republic	0.03	0.03	902
Haiti	0.01	0.01	733
<i>Others</i>	0.01	0.01	809
<i>World</i>	4.75	3.68	774

Source: FAO Stat (2012)



production. The other countries with notable pigeonpea production are Myanmar and Nepal in Asia; Malawi, Kenya, Uganda, Tanzania and Congo in Africa; and the Dominican Republic and Haiti in the Caribbean region.

*India:* In India, pigeonpea occupies an area of about 3.47 million ha with a total production of 2.46 million tonnes, with an average productivity of 711 kg/ha. It is grown mostly as a rainfed crop in dryland areas. However, it is also grown under irrigated conditions in about 0.16 million ha mostly in Uttar Pradesh, Gujarat, Karnataka, Tamil Nadu, Maharashtra, Madhya Pradesh and Bihar. The state-wise area, production and productivity of pigeonpea is given in Table 8.2. Among the states, Maharashtra leads in both area and production followed by Karnataka. The other prominent states growing pigeonpea are Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Gujarat and Odisha. The highest productivity is observed in Bihar followed by Gujarat. Besides these

**Table 8.2** State-wise area (million ha), production (million tonnes) and productivity (kg/ha) of pigeonpea in India (2009-10)

Zone/State	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
Maharashtra	1.09	0.92	841
Karnataka	0.60	0.28	467
Andhra Pradesh	0.46	0.20	438
Madhya Pradesh	0.36	0.31	851
Uttar Pradesh	0.31	0.20	662
Gujarat	0.27	0.24	906
Odisha	0.13	0.11	841
Jharkhand	0.06	0.05	871
Bihar	0.03	0.04	1,513
Tamil Nadu	0.03	0.02	766
Others	0.12	0.08	-
All-India	3.47	2.46	711

Source: GOI (2012)

two states, Maharashtra, Madhya Pradesh, Odisha, Jharkhand and Tamil Nadu have higher productivity than the national average. The other states have lower productivity than the national average.

### Greengram

Greengram [*Vigna radiata* (L.) Wilczek; syn. *Phaseolus radiatus* L., *Phaseolus aureus* Roxb., *Vigna aureus* (Roxb.) Hepper, *Rudia aureus* (Roxb.) Maekawa, and *Azukia radiata* (L.) Ohwi] commonly known as mungbean or goldengram is one of the most important short-duration pulse crops grown in India. It ranks third among all pulses grown in India after chickpea and pigeonpea. It is quite versatile crop grown for seeds, green manure and forage; as mixed or sole crop either on residual moisture of the previous crop or as a catch crop to make use of the land left fallow between two main season crops. It makes a good green manure if incorporated into soil. Further, it enriches the



soil by atmospheric nitrogen fixation through root nodules. The seeds are highly nutritious with protein (23-24%), carbohydrates, minerals and vitamins.

*World:* Greengram is the most widely distributed and cultivated Asiatic species. It is widely cultivated throughout the south and south-east Asia including India, Pakistan, Bangladesh, Sri Lanka, Thailand, Laos, Cambodia, Vietnam, Indonesia, Malaysia, South China and Taiwan. It is also cultivated to a lesser extent in many parts of Africa, USA and Australia.

*India:* Greengram is grown in about 3.109 million ha in India with a total production of 0.946 million tonnes. Among the states growing this crop, Rajasthan ranks first in area, while Maharashtra ranks first in production. Punjab is the leading state in productivity with 805 kg/ha vis-a-vis the national average of 304 kg/ha. The data on area, production and productivity of the major states growing greengram are given in Table 8.3.

### Blackgram

Blackgram [*Vigna mungo* (L.) Hepper; syn. *Phaseolus mungo* L. and *Azuki mungo* (L.) Masamune], also known as urdbean, mash, mungobean, black mape etc., is another important short-duration pulse crop grown in many parts of India. This crop is grown in cropping systems as a mixed crop, catch crop, sequential crop besides growing as a sole crop under residual moisture conditions after the harvest of rice and also before and after the harvest of other summer crops under semi-irrigated and dryland conditions. Its seeds are highly nutritious with protein (25-26%), carbohydrates, minerals and vitamins. Seeds are used in the preparation of many popular dishes. It is one of the most important components in the preparation of famous south Indian dishes, viz. *dosa*, *idli*, *vada* etc.

*World:* The blackgram area is mostly restricted to wet tropics. It is grown in India, Pakistan, Sri Lanka, Burma and some countries of south-east Asia, Africa and America. In West Indies, it is grown mainly as a green manure under the name wolly pyrol. There are no comprehensive and accurate production statistics compiled on international basis for either blackgram or greengram. Compilation of accurate statistics is made difficult by the nature of production and trade in these crops. Mostly they are grown on small holdings, often as mixed or intercrops, and utilized and/or traded locally.

*India:* In India, it is grown on an area of about 2.969 million ha with a total production of 1.243 million tonnes with an average productivity of 419 kg/ha. Uttar Pradesh leads with the highest area while Andhra Pradesh leads with highest production among the states. The area, production and productivity of different states in India are furnished in Table 8.4.

### Cowpea

Cowpea [*Vigna unguiculata* (L.) Walp., syn. *Vigna sinensis* (L.) Savi ex Hassk], commonly known in India as *lobia*, is also known by name crowder pea, black eyed pea, southern pea etc. in different countries of the world. It is one of the important *kharif* pulses grown in India for grain, forage, green manure and as exhaustive crop in soil fertility and nutrition experiments in



Table 8.3 State-wise area (lakh ha), production (lakh tonnes) and productivity (kg/ha) of greengram in India (2005-06)

State	Kharif			Rabi/Summer*			Total		
	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity
Rajasthan	7.995	1.300	163	-	-	-	7.995	1.300	163
Maharashtra	5.350	1.890	354	0.120	0.049	408	5.470	1.939	354
Karnataka	3.930	0.870	221	0.070	0.030	429	4.000	0.900	225
Andhra Pradesh	2.520	1.247	495	1.330	0.420	316	3.850	1.667	433
Odisha	1.250	0.237	190	1.323	0.425	321	2.573	0.662	257
Bihar	0.083	0.052	627	1.741	0.952	553	1.824	1.014	556
Gujarat	1.729	0.535	309	-	-	-	1.729	0.535	309
Tamil Nadu	0.383	0.141	368	0.984	0.318	323	1.367	0.459	336
Madhya Pradesh	0.763	0.248	325	0.032	0.009	281	0.795	0.257	323
Uttar Pradesh	0.292	0.078	267	0.396	0.282	712	0.688	0.360	523
Chhattisgarh	0.099	0.027	273	0.073	0.017	233	0.172	0.044	250
Haryana	0.141	0.061	433	-	-	-	0.141	0.061	433
Punjab	0.123	0.099	805	-	-	-	0.123	0.099	805
Jharkhand	0.122	0.057	467	-	-	-	0.122	0.057	467
West Bengal	0.007	0.004	571	0.108	0.042	389	0.115	0.046	400
Asom	-	-	-	0.075	0.034	453	0.075	0.034	453
Jammu and Kashmir	0.018	0.009	500	-	-	-	0.018	0.009	500
Puducherry	0.018	0.006	333	0.003	0.002	667	0.011	0.007	636
Tripura	0.008	0.005	625	-	-	-	0.008	0.006	750
Kerala	0.008	0.006	750	-	-	-	0.008	0.006	750
Himachal Pradesh	0.004	0.001	250	-	-	-	0.004	0.001	250
India	24.815	6.867	277	6.273	2.596	414	31.088	9.463	304

\* Bihar and Uttar Pradesh

Source: DPD (2012)

Table 8.4 State-wise area (lakh ha), production (lakh tonnes) and productivity (kg/ha) of blackgram in India (2005-06)

State	Kharif			Rabi/Summer*			Total		
	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity
Uttar Pradesh	4.920	2.113	429	0.466	0.277	594	5.386	2.390	444
Maharashtra	4.680	1.990	425	0.120	0.074	617	4.800	2.064	430
Madhya Pradesh	4.434	1.567	353	0.063	0.009	281	4.497	1.576	350
Andhra Pradesh	0.792	0.348	439	3.420	2.160	632	4.212	2.508	595
Tamil Nadu	0.488	0.152	311	1.667	0.556	334	2.155	0.708	329
Rajasthan	1.385	0.351	253	-	-	-	1.385	0.351	253
Odisha	1.272	0.312	245	0.061	0.025	410	1.333	0.337	253
Chhattisgarh	1.134	0.329	290	0.062	0.015	242	1.196	0.344	288
Karnataka	1.010	0.190	188	0.110	0.050	455	1.120	0.240	214
Gujarat	0.959	0.363	379	-	-	-	0.959	0.363	379
Jharkhand	0.722	0.382	529	-	-	-	0.722	0.382	529
West Bengal	0.486	0.307	632	0.085	0.102	1200	0.571	0.409	716
Asom	0.354	0.173	489	-	-	-	0.354	0.173	489
Uttarakhand	0.330	0.200	606	-	-	-	0.330	0.200	606
Bihar	0.252	0.194	770	-	-	-	0.252	0.194	770
Jammu and Kashmir	0.155	0.065	419	-	-	-	0.155	0.065	419
Himachal Pradesh	0.113	0.046	407	-	-	-	0.113	0.046	407
Sikkim	0.001	0.001	1000	0.039	0.028	718	0.040	0.029	725
Punjab	0.028	0.013	464	-	-	-	0.028	0.013	464
Haryana	0.023	0.008	348	-	-	-	0.023	0.008	348
Tripura	0.013	0.007	538	0.004	0.002	500	0.017	0.009	529
Punducherry	-	-	-	0.017	0.005	294	0.017	0.005	294
Dadra and Nagar Haveli	0.016	0.015	938	-	-	-	0.016	0.015	938
Kerala	0.007	0.005	714	-	-	-	0.007	0.005	714
India	23.220	8.958	386	6.468	3.492	540	29.688	12.434	419

\*Uttar Pradesh  
Source: DPD (2012)



agronomic research. Cowpea seeds are highly nutritious with high protein (23-24%), carbohydrates, minerals and vitamins.

*World:* Cowpea is grown throughout the tropics and sub-tropics as a grain legume mainly for dry beans, green vegetables, forages and as a cover crop. Its major area, however, is in Africa. It is also cultivated in a few countries of Asia, Americas, Australia and Europe. The data on area and production for different countries are presented in Table 8.5.

**Table 8.5** Area (million ha), production (million tonnes) and productivity (kg/ha) of cowpea in different countries (2010 )

Country	Area (million ha)	Production (million tonnes)	Productivity (kg/ha)
Niger	5.63	1.80	320
Nigeria	2.52	2.24	890
Burkina Faso	0.77	0.43	558
Mali	0.25	0.11	434
Sudan	0.20	0.05	225
Kenya	0.17	0.07	430
United Republic of Tanzania	0.16	0.09	563
Cameroon	0.13	0.14	1,023
Democratic Republic of Congo	0.13	0.06	462
Senegal	0.13	0.05	381
Myanmar	0.13	0.17	1,353
Malawi	0.12	0.08	695
Uganda	0.08	0.09	1,063
Haiti	0.04	0.03	676
Mauritania	0.02	0.01	461
Peru	0.02	0.03	1,513
United States of America	0.01	0.07	4,669
Sri Lanka	0.01	0.01	1,068
Madagascar	0.01	0.01	883
Serbia	0.01	0.02	3,798
World	10.56	5.57	527

*Source: FAO Stat (2012)*

*India:* In India, it is a popular crop among farmers in many states throughout the country. However, the major area is concentrated in the states of Karnataka, Andhra Pradesh, Uttar Pradesh and Bihar. Cowpea is mostly raised as a mixed crop along with either cereals or oilseed crops. Exact information on area, production and productivity for different states is not available.

### Horsegram

Horsegram [*Macrotyloma uniflorum* (Lam.) Verdc. syn. *Dolichos uniflorus* Lam. and *Dolichos biflorus* auct. non Linn.] is one of the very hardy leguminous crops grown in India. It is also known as *hurali*, *kulthi*, *Gahat*, Madras gram etc. It is cultivated for several purposes, namely for seeds, for fodder and as

## Kharif Pulse

green-manure crop. The grains are used in the preparation of many delicacies like *sambar*, curry etc. It is also known to possess medicinal value and is considered to be an important ingredient in many *ayurvedic* preparations. The vegetative portion is considered to be a high-quality fodder for animals. Further the seeds are used to feed the high value animals like horses, bullocks, miltch animals from time immemorial. Seeds are rich in protein (22-23%) and calcium.

Horsegram is grown in India, Myanmar, Nepal, Malaysia, Mauritius, Sierre Leone, West Indies etc. for varied purposes like for seeds, fodder, green manuring etc. Its trade is also limited to local markets. Hence there are no data available at global level about area and production. In India it is grown in many states (Table 8.6) spread across different agro-climatic conditions from ancient times. Karnataka leads both in area and production followed by Odisha, Maharashtra, Tamil Nadu etc. The highest productivity is observed in Bihar followed by Kerala.

### Mothbean

Mothbean [*Vigna aconitifolia* (Jacq.) Marechal; syn. *Phaseolus aconitifolius* Jacq.], also called *matki*, *Math*, dew bean, mat bean, or Turkish gram in some parts of the world, is native to Indian sub-continent. It is an important pulse crop of arid and semi-arid regions of India. It has multi-uses and adapts to extremes or uncongenial ecological niches particularly, in areas receiving fewer rains with erratic distribution. In India mothbean is generally consumed as a rich source of protein (22-24%). The seed is cooked whole or split and the green pods can be cooked and eaten as vegetables. Seeds are also processed in *dal* (a sprouted bean paste) or *bhujia* (a salted snack).

Mothbean is a minor crop cultivated in India, Pakistan, Myanmar, southern China and western USA. The data on area, production and productivity are not available at global level. In India, it is one of the important crops cultivated during *kharif* season. Although cultivated in many states in India, it is mostly concentrated in the western part of the country. Rajasthan leads both in area and production, followed by Maharashtra and Gujarat. The productivity has been the highest in Punjab. Except for Rajasthan all other states have productivity higher than the national average (Table 8.7).

## TAXONOMY AND VARIETAL DEVELOPMENT

### Pigeonpea

Various types of pigeonpea cultivars differing in plant height, colour of flower and seed, growth habit, pod and seed shape and size, life span and time of maturity have been identified. The long-duration perennial types appear like tree while the short-duration annuals are small and seasonal. Thus the varieties of the crop cultivated in India have been grossly divided into two chief types '*tur*' and '*arhar*' with numerous intermediate forms (De, 1974). Many researchers have recognized these types as:

1. *Cajanus cajan* var. *flavus* (DC.) Purseglobe (*Tur*) : This includes short-duration annuals having smaller plants, usually yellow flowers and fewer plain pods. These are grown as field crop mainly for seed in southern India.



State	Kharif			Rabi/Summer			Total		
	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity
Karnataka	1.250	0.730	584	1.450	0.580	400	2.700	1.310	485
Odisha	0.750	0.209	279	0.004	0.001	250	0.754	0.210	279
Maharashtra	0.543	0.174	320	0.109	0.049	450	0.652	0.223	342
Tamil Nadu	0.059	0.036	610	0.545	0.184	338	0.604	0.220	364
Andhra Pradesh	0.099	0.041	414	0.470	0.160	340	0.569	0.201	353
Chhattisgarh	0.509	0.159	312	0.031	0.009	290	0.540	0.168	311
Madhya Pradesh	0.288	0.082	285	0.006	0.002	333	0.294	0.084	285
Jharkhand	0.178	0.073	410	.	.	.	0.178	0.073	410
Kerala	.	.	.	0.040	0.033	825	0.040	0.033	825
West Bengal	.	.	.	0.028	0.013	464	0.028	0.013	464
Bihar	0.113	0.097	858	.	.	.	0.113	0.097	858
Himachal Pradesh	0.024	0.010	417	.	.	.	0.024	0.010	417
Jammu and Kashmir	0.020	0.006	300	.	.	.	0.020	0.006	300
India	3.813	1.611	423	2.683	1.031	384	6.496	2.642	407

Source : DPD (2012)

**Table 8.7** State-wise area (lakh ha), production (lakh tonnes) and productivity (kg/ha) of mothbean in India in 2005-06

State	Total		
	Area	Production	Productivity
Rajasthan	12.278	1.494	122
Maharashtra	0.420	0.120	286
Gujarat	0.410	0.110	268
Haryana	0.058	0.010	172
Uttar Pradesh	0.033	0.001	333
Jammu and Kashmir	0.028	0.017	607
Punjab	0.001	0.001	1,000
India	13.198	1.753	133

Source : DPD (2012)

2. *Cajanus cajan* var. *bicolor* (DC.) Purseglobe (*Arhar*): This includes long-duration, late-maturing types having tall growth and bushy habit. Flowers are yellow with purple streak. The standard petal bears red veins on the dorsal side. Pods are dark coloured with four to five seeds. These types yield well in the first season and decline in the later years. It is also found suitable for forage, as cover crop, shade and for hedge crop. This is more prevalent in northern India.

Varietal improvement work in pigeonpea was started way back in 1917 and a large number of improved varieties have been released periodically. Many varieties suitable to different agro-climatic conditions, resistant to pests and diseases have been developed. Breeding work is now underway to identify and produce short-duration varieties and hybrids. Based on the time required for maturity all the varieties have been classified in to three groups, viz. (i) short duration—100-150 days, (ii) medium duration — 150-180 days and (iii) long-duration—180-300 days. Some of the important varieties released for cultivation in different zones have been listed in Table 8.8

**Table 8.8** Improved pigeonpea varieties released for cultivation in different zones in India

Zone	Variety	Year of release	Area of adoption	Special character
Northern Hill Zone (Hills of H.P., J&K and Uttarakhand)	Pusa Ageti	1974	Whole zone	SD
	T 21	1974	Whole zone	SD
	UPAS 120	1976	Whole zone	SD
	ICPL 151	1989	Jammu region	SD
	ICPL 85010	1994	Plains of H.P.	SD
	VL Arhar 1	2007	Uttarakhand	-
North Western Plains Zone (Delhi, Punjab, Western U.P.,	T 21	1974	Whole zone	SD
	UPAS 120	1976	Whole zone	SD
	Manak	1981	Whole zone	SD
	AL 15	1982	Punjab	SD, DPT

Table 8.8 contd



Table 8.8 contd

Zone	Variety	Year of release	Area of adoption	Special character
northern	Pusa 33	1987	Whole zone	SD
Rajasthan and Haryana)	ICPL 151	1989	Whole zone	SD
	Birsa Arhar 1	1992	Whole zone	WR
	Pusa 855	1993	Whole zone	SD
	Paras (H 82-1)	1993	Whole zone	SD
	AL 201	1993	Punjab	SD
	PPH 4 (Hybrid)	1994	Punjab	SD
	Pusa 991	2003	Delhi	WR, PBR, SMR
	Pusa 992	2003	Whole zone	-
	Pusa 2001	2006	Delhi	WT, SMT, PBT
	Pusa 2002	2008	Whole zone	-
	PAU 881	2008	Whole zone	-
	Pant Arhar 291	2010	Uttarakhand	-
North Eastern Plains Zone (Central and Eastern U.P., Bihar, W.B. and Asom)	T 21	1974	Whole zone	SD
	UPAS 120	1976	Whole zone	SD
	T 17	1978	U.P.	LD
	B 517	1982	W.B.	LD
	B 7	1982	W.B.	LD
	Bahar	1986	Whole zone	LD, SMR, PR
	DA 11	1986	Bihar	AR, PR
	T 7	1988	U.P.	LD
	Birsa Arhar 1	1992	Bihar plains	MD, WR
	Pusa 9	1993	Whole zone	LD, PR
	NDA 88-2	1997	U.P.	SMR,WR, PBR
	Amar (KA -32- 1)	1997	U.P.	SMR
	Azad ( K 91-25)	1999	U.P., Bihar	WR, SMR
	MA 6	2003	Whole zone	Late sowing
	NDA 98-1	2008	U.P.	-
Central Zone (M.P., Rajasthan, Maharashtra and Gujarat)	T 21	1974	Whole zone	SD
	BDN 1	1976	Maharashtra	MD, WR
	BDN 2	1976	Maharashtra	MD,WR
	JA 3	1982	M.P.	-
	Pusa 74	1982	Whole zone	SD
	No. 148	1982	Whole zone	MD
	PT 301	1982	Whole zone	MD
	C 11	1982	Whole zone	MD,WR
	PT 221	1982	Whole zone	MD
	Hy 185	1982	Whole zone	MD
	TT 6	1983	Whole zone	MD,WR
	T 15-15	1985	Gujarat	MD
	TAT 10	1985	Maharashtra	SD
	ICPL 8863	1985	Maharashtra	WR
	ICPL 87	1986	Whole zone	SD

Table 8.8 contd

Table 8.8 contd

Zone	Variety	Year of release	Area of adoption	Special character
	Pusa 33	1988	Whole zone	
	ICPL 151	1989	Whole zone	SD
	BSMR 175	1991	Maharashtra	SD
	ICPH 8 (Hybrid)	1991	Whole zone	MD
	JA 4	1991	M.P.	SD
	Gujarat Tur 100	1992	Gujarat	MD
	Sharad (DA 11)	1994	Maharashtra	MD
	ICPL 87119	1994	Whole zone	-
	KM 7	1995	Maharashtra	WR
	BSMR 736	1996	Maharashtra	MD
	AKPH 4101 (Hybrid)	1997	Whole zone	MD
	MA 3	1999	M.P., Gujarat, Maharashtra	- PFT
	AKT 8811	2000	Maharashtra	-
	Vaishali(BSMR 853)	2002	Maharashtra	WR, SMR
	GTH 1 (Hybrid)	2004	Whole zone	
	Amol (BDN 708)	2007	Maharashtra	WR, SMR
	Vipul	2007	Maharashtra	SMR, WR
	TJT 501	2009	Whole zone	-
South Zone (Odisha, A.P., Karnataka and T.N.)	BDN 2	1976	A.P.	MD, WR
	C 11	1982	A.P.	MD, WR
	Hy 3A	1982	Whole zone	MD
	Hy 3C	1982	Whole zone	MD, SMR
	LRG 30	1982	Whole zone	MD
	GS 1	1982	Karnataka	LD
	PT 221	1982	Karnataka	MD
	SA 1	1985	Whole zone	LD
	ICPL 87	1986	Whole zone	SD
	ICPL 8863	1986	A.P.	WR
	TTB 7	1988	Karnataka	MD
	ICPL 332	1989	A.P.	-
	Co 6	1991	T.N.	PBT LD
	Vamban 1	1992	T.N.	SD,WR
	TT 6	1993	Whole zone	MD
	KM 7	1994	Whole zone	SD
	CoH 1 (Hybrid)	1994	T.N.	WR
	TS 3	1995	Karnataka	-
	CoPH 2(Hybrid)	1997	T.N.	SD
	ICPL 85010	1998	A.P.	SD,DPT
	Durga (ICPL 84031)	1999	A.P.	
	Vamban 2	2000	T.N.	SMR
	APK 1 (ARG 102)	2000	T.N.	SMR, WR
	Laxmi (ICPL 85063)	2001	A.P.	-
	Sel. 31	2002	Karnataka	

Table 8.8 contd



Table 8.8 concluded

Zone	Variety	Year of release	Area of adoption	Special character
	BRG 1	2006	Karnataka	MD
	Vamban 3	2006	T.N.	-
	PRG 158	2007	A.P.	-
	BRG 2	2009	Karnataka	-
	Surya (MRG 1004)	2009	A.P.	-

H.P., Himachal Pradesh; J&K, Jammu and Kashmir; U.P., Uttar Pradesh; W.B., West Bengal; M.P., Madhya Pradesh; A.P., Andhra Pradesh; T.N., Tamil Nadu. SD, Short duration; MD, medium duration; LD, long duration; DPT, determinate plant type; PBT, *Phytophthora* blight tolerant; SMR, sterility mosaic resistant; AR, *Alternaria* resistant; WR, Wilt resistant; PB, pod-borer tolerant; PFT, pod-fly tolerant.

The hybrid technology, based on cytoplasmic nuclear male-sterility (CMS) system, has given an opportunity of achieving the long-cherished goal of breaking yield barrier in pigeonpea through high-yielding hybrids. In the last few years, the ICRISAT and ICAR have tested over 1000 experimental hybrids. In the on-farm trials conducted in the states of Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, and Jharkhand during 2007, 2008 and 2009 have demonstrated >30% yield advantage of hybrids over local check varieties (Table 8.9).

Table 8.9 Grain yield (kg/ha) of a hybrid and an improved variety (Mean of 43 locations)

Year	ICPH 2671 (Hybrid)	Maruti (Variety)	Increase %
2005	3,183	1,855	71.59
2006	2,694	2,066	30.40
2007	2,702	2,140	26.26
2008	2,022	1,746	15.81
Mean	2,650	1,952	35.76

Source: Saxena and Nadarajan (2010)

### Greengram

More than 2,000 strains and several botanical varieties of greengram have been recognized. Over 1,000 cultivars are grown in China and other Asiatic countries. They differ mainly in habit, size of plant, period of maturity, colour of pods, size and colour of seeds.

Greengram improvement work began as early as 1925 with selections from different locations throughout the country. Many improved high yielding, disease and pest-resistant, short-duration and short-stature varieties suitable to varied agro-climatic conditions have been developed. Now there are specific varieties for almost all greengram-growing areas throughout the country. A list of some promising varieties for different zones is furnished in Table 8.10.

### Blackgram

Kay (1979) has identified two main types of blackgram.

1. Large-seeded early maturing black seeded types: *Vigna mungo* var. *niger*
2. Small-seeded late maturing types with colours varying from brown, olive green to grey to mottled : *Vigna mungo* var. *viridis*

Blackgram is distributed mainly in tropical to sub-tropical countries where it is grown mainly in summer season.

**Table 8.10** Improved greengram varieties released for cultivation in different zones in India

Zone	Variety	Year of release/ notification	Area of adoption	Special character
Northern Hill Zone (Hills of H.P., J&K and Uttarakhand)	Pusa Baisaki	1974	Whole zone	
	PS 16	1980	Whole zone	
	K 851	1984	Whole zone	
	PDM 54	1987	Whole zone	
	Pusa Vishal	2001	Whole zone	YMR
	Sweta (KM 2241)	2008	Whole zone	YMR
	Pant Mung 5	2009	Uttarakhand	
	Pusa 06722	2010	J&K, Manipur, Tripura	YMR, CLSR
North Eastern Plains Zone (Central and Eastern U.P., Bihar, W.B. and Asom)	Amrit	1978	Bihar	YMR, CLSR
	Sunaiana	1978	Bihar	CLST
	Sonali	1982	W.B.	
	Pant Mung 1	1983	Whole zone	YMR
	ML 337	1985	Whole zone	
	PDM 54 (Moti)	1987	Whole zone	
	PDM 11	1987	Whole zone	Spring
	PDM 84-143	1990	Eastern zone	
	Narendra Mung 1	1992	U.P.	
	UPM 92-1	1997	Whole zone	
	HUM 2 (Malaviya Jagrati)	2000	U.P.	Summer
	PDM 139 (Samrat)	2001	U.P.	Summer
	HUM 6 (Malviya Janpriya)	2001	U.P.	Spring/Summer YMR, RRR
	HUM 12 (Malaviya Janchetna)	2003	Whole zone	YMR, CLSR
	Meha	2004	Whole zone	Spring, YMR
	TMB 37	2005	Whole zone	YMR
HUM 16 (Malaviya Jankalyani)	2006	Whole zone	YMR, RKNR	
North Western Plains Zone (Delhi, Punjab, Western U.P., northern Rajasthan and Haryana)	G 65	1973	Punjab	Summer
	ML 5	1978	Whole zone	
	ML 131	1982	Punjab	YMR, CLSR
	SML 32	1982	Punjab	
	Mung Gujarat 1	1984	Gujarat	CLSR, YMR
	ML 337	1985	Whole zone	
	S 9	1985	Haryana	
	Pant Mung 3	1985	Whole zone	YMR, CLSR
	ML 267	1987	Whole zone	YMR
	Pusa 105	1987	Whole zone	
RMG 62	1991	Rajasthan		

Table 8.10 contd



Table 8.10 contd

Zone	Variety	Year of release/ notification	Area of adoption	Special character
	Asha	1993	Haryana	
	MH 88-111	1993	Whole zone	
	ML 613	1996	Punjab	
	Pant Mung 4	1997	Whole zone	YMR, CLSR, BLSR
	RMG 268	1999	Rajasthan	
	Samrat	2001	U.P.	CLST
	Ganga 8 (Gangotri)	2001	Whole zone	YMR
	Pusa 9531	2001	Whole zone	YMR, CLSR, BLBR, LCR
	Pusa Vishal	2001	Whole zone	Summer
	RMG 344 (Dhanu)	2001	Rajasthan	YMR
	SML 668	2002	Punjab	Summer
	GM 4	2003	Gujarat	YMR, RKNT,
	RMG 492	2003	Rajasthan	Spring
	Ganga 1(Jamnotri)	2004	Rajasthan	Sping, YMR, YMR, CLSR, PMR, BLBR
	MH 215	2007	Whole zone	YMR
	MH 125	2009	Haryana	
	IPM 02-3	2009	Whole zone	YMR
<i>Central Zone</i> (M.P., Rajasthan, Maharashtra and Gujarat)	Jawahar 45	1974	M.P.	
	ML 131	1982	Whole zone	
	Jalgaon 781	1982	Maharashtra	
	TAP 7	1983	Maharashtra	
	Pant Mung 2	1983	Whole zone	
	Sabarmati	1984	Gujarat	PMT, LST
	ML 337	1985	Whole zone	
	PDM 11	1987	Whole zone	Spring, YMR
	Pusa 105	1987	Whole zone	
	BM 4	1992	Whole zone	
	Phule M 2	1992	Maharashtra	
	Mung Gujarat 1	1994	Gujarat	
	HUM 1	1995	Whole zone	Spring, YMR, CLSR
	TARM 1	1997	Whole zone	Rabi
	TARM 18	1997	Maharashtra	PMR, MPBR
	JM 721	1996	M.P.	CLSR, PMR
	Pusa 9531	2000	Whole zone	Summer, YMR
	BPMR 145	2001	Maharashtra	PMR, MPBR
	Vaibhav (Phule M 9339)	2002	Maharashtra	PMR
	BM 2002-1	2005	Maharashtra	PMR
<i>South Zone</i>	Kondaveedu	1982	A.P.	

Table 8.10 contd

Table 8.10 concluded

Zone	Variety	Year of release/ notification	Area of adoption	Special character
(Odisha, A.P., Karnataka, T.N. and Kerala)	KM 1	1982	T.N.	
	KM 2	1982	T.N.	
	Co 4	1984	T.N.	TBR, PMR, RRR, YMR
	Sujata	1984	Odisha	YMR
	Jyoti	1985	Odisha	YMR
	Dhauri	1985	Odisha	CLST, PMR
	Ratila Sel.	1985	Odisha	
	Co 2	1985	T.N.	
	Co 3	1985	T.N.	
	Paiyur 1	1985	T.N.	
	PDM 54	1987	Whole zone	
	Vamban 1	1989	T.N.	
	PDM 84-143	1990	Whole zone	
	ADT 3	1991	T.N.	
	Co 5	1991	T.N.	
	Pusa 9072	1995	Whole zone	Rabi
	HUM 1	1995	Whole zone	Spring
	TARM 1	1995	Whole zone	Rabi
	K 1	1999	T.N.	YMR, CLSR
	Eksila (WGG 37)	1999	A.P.	Rabi, YMR
	Co 6 (COGG 902)	2000	T.N.	All seasons, YMR
	LAM 460	2001	A.P.	YMR
	VRM (GG 1)	2001	T.N.	YMR
	VBN (GG 2)	2001	T.N.	All season, YMR
	COGG 912	2005	Whole zone	-
	KKM 3	2009	Karnataka	
	Madira Pesara 347	2009	A.P.	
	PKV AKM 4 (AKM 9904)	2011	Whole zone	

H.P., Himachal Pradesh; J&K, Jammu and Kashmir; U.P., Uttar Pradesh; W.B., West Bengal; M.P., Madhya Pradesh; A.P., Andhra Pradesh; T.N., Tamil Nadu

BLBR, Bacterial leaf blight resistant; CLSR/T, *Cercospora* leaf spot resistant/tolerant; LCR, leaf curl resistant; LST, leaf spot tolerant; MPBR, *Macrophomina* blight resistant; PMR/T, powdery mildew resistant/tolerant; RKNR, root-knot nematode resistant; RRR, root rot resistant; TBR, Tip blight resistant; YMR, Yellow mosaic resistant

Breeding efforts to develop improved, high yielding varieties in blackgram have resulted in many varieties with desired traits. Varieties identified for the superiority have been released for cultivation in different areas. The suitable varieties for different zones are presented in Table 8.11.



**Table 8.11** Improved blackgram varieties released for cultivation in different zones in India

Zone	Variety	Year of release	Area of adoption	Special character
<i>Northern Hill Zone</i> (Hills of H.P., J&K and Uttarakhand)	MASH 1-1	1973	J & K	
	T 9	1975	Whole zone	
	Kullu Mash	1975	H.P.	
	Pant U 19	1982	Whole zone	
	VB 3	1995	Whole zone	
	UG 218	1998	H.P.	YMR
	NDU 99-2	2003	Whole zone	YMR
<i>North Eastern Plains Zone</i> (Central and Eastern U.P., Bihar, W.B. and Asom)	T 9	1975	Whole zone	
	Navin	1978	Bihar	
	Pant U 19	1982	Whole zone	
	Narendra Urd 1	1993	U.P.	
	PDU 88-108	1983	Whole zone	
	WBU 108	1995	Whole zone	
	PDM 54	1987	Whole zone	
	Azad Urd 1 (KU 91-2)	1999	Whole zone	YMR, RRR
	IPU-94-1	2000	Whole zone	YMR, CLSR
	Azad Urd 2 (KU 91)	2001	U.P.	Spring
Goutam (WBU 105)	2004	W.B.		
WBU 109	2008	Whole zone	Spring, YMR	
<i>North Western Plains Zone</i> (Delhi, Punjab, Western U.P., northern Rajasthan and Haryana)	T 9	1975	Whole zone	
	G 75	1978	Punjab	
	Pant U 19	1982	Punjab	
	PDU 1 (Basant Bahar)	1991	Whole zone	Spring
	Pant U 35	1987	Uttarakhand	
	WBU 108	1995	Whole zone	
	Shekhar 2 (KU 300)	2001	Whole zone	YMR, CLSR, RRR
	Gujarat Urd 1	2006	Gujarat	PMR, CLSR
	Pant Urd 31	2006	U.P.	
	Mash 114	2010	Punjab	YMR,
	Mash 479 (KUG 479)	2011	Whole zone	
<i>Central Zone</i> (M.P., Rajasthan, Maharashtra and Gujarat)	T 9	1975	Whole zone	
	PDU 1	1991	Whole zone	Spring
	Pant U 30	1982	Whole zone	YMR
	Sindhkheda 1-1	1982	Maharashtra	
	Zandewal	1984	Gujarat	
	Jawahar Urd 2	1987	M.P.	

Table 8.11 contd

Table 8.11 concluded

Zone	Variety	Year of release	Area of adoption	Special character
	Jawahar Urd 3	1987	M.P.	
	TPU 4	1992	Whole zone	
	TAU 2	1993	Maharashtra	
	VB 3	1995	Whole zone	
	Barkha (RBU 38)	1999	Whole zone	
	KU 96-3	2003	Whole zone	YMR
<i>South Zone</i>	Khargone 3	1976	Karnataka	
(Odisha, A.P.,	Co 2	1978	T.N.	
Karnataka,	KM 2	1982	T.N.	
T.N. and Kerala)	TMV 1	1982	T.N.	
	Co 5	1984	T.N.	
	ADT 3	1984	T.N.	
	Sarala	1985	Odisha	
	LBG 17	1991	Whole zone	Rabi, PMR
	LBG 402	1991	Whole zone	Rabi
	Pant U 30	1982	Whole zone	YMR
	LBG 20	1991	A.P.	
	Vamban 1	1991	T.N.	
	ADT 4	1991	T.N.	
	ADT 5	1991	T.N.	
	Vamban 3	1995	Whole zone	
	WBG 26	1995	Whole zone	
	KBG 512	1997	T.N.	Rabi
	Shekar 1 (KU 301)	1998	Whole zone	YMR, PMR
	Trombay Urd 94-2 (TU 94-2)	1999	Whole zone	YMR, PMR
	Suman Jana	2002	Kerala	
	APK 1	2001	T.N.	Rabi
	LAM 623 (LBG 623)	2001	A.P.	All seasons, YMR
	Ujala (OBG 17)	2005	Odisha	Rabi, YMR, PMR
	LAM 709	2007	A.P.	
	Madira Minumu 207	2009	A.P.	-
	IPU 02-43	2009	Whole zone	YMR, PMR
	VBN (Bg) 5	2009	T.N.	All seasons, YMR, PMR
	Co 6	2011	Whole zone	
	Mash 391 (LU 391)	2011	Whole zone	

H. P., Himachal Pradesh; J & K, Jammu and Kashmir; U.P., Uttar Pradesh; W.B., West Bengal; M.P., Madhya Pradesh; A.P., Andhra Pradesh; T.N., Tamil Nadu

CLSR, *Cercospora* leaf spot resistant; PMR, powdery mildew resistant; RRR, root rot resistant; YMR, yellow mosaic resistant



### Cowpea

The genus *Vigna* of the tribe Phascolae is believed to be pan-tropical and comprises about 160 species distributed mostly in Africa and Asia. It is likely that cowpea was dispersed from Africa to Asia with human migrations in more recent times. In India forms described as sub-species *cylindrica* evolved from sub-species *unguiculata*. Typical cultivars of sub-species *sesquipedalis* were derived in south-east Asia from vegetable types selected from sub-species *unguiculata* in India. Steele (1976) opined that cowpea was established in West Africa some time after 3000 bc, and it reached India between approximately 1500 and 1000 bc, the Far East during the first millennium bc and southern Europe prior to 300 bc. The Spanish (and probably also the Portuguese) introduced the cowpea to the New Zealand where it became widespread. *Vigna unguiculata* is the only cultivated species of Africa.

The cultivated forms of cowpea are categorized as:

Sub-genus: *Vigna*

(i). Sub-sps: *unguiculata*

*Vigna unguiculata* (L.) Walp.: Cultivars can be roughly grouped in to 4 cultigroups:

(a) cv.gr. *biflora* and (b) cv.gr. *catjang*

These bear small-seeded erect pods and are grown mostly in south and south-east Asia.

(c) cv.gr. *sesquipedalis*

Also called yard long bean or asparagus bean. Very long drooping pods eaten as green vegetable

(d) cv.gr. *textilis*

These have very long, stout peduncles, which are used for extracting textile fibre.

(ii). Sub-sps: *dekentiana* (Harms) Verdc.

var. *dekentiana* : most common wild form

var. *mensensis* (Schweinf.) M.M. et S: Large flowers and long calyx lobes

var. *pubescens* (R. Wilczek) M.M. et S: Short pubescence on leaves and stalks

var. *protracta* (E. Mey.) Verdc.: Small leaflet with long pubescence

(iii). Sub-sps: *tennis* (E. Mey.): Small glabrescent lobed leaflets

(iv). Sub-sps: *Stenophylla* (Havary): Narrow nastily leaflets

In India, cowpea (*Vigna unguiculata* var. *unguiculata*) has a very wide range of agro-ecological distribution extending from tropical conditions in southern peninsular region to northern geographical limits to the lower Himalayas. It is endowed with genetic diversity in its forms; *V. unguiculata* var. *unguiculata* and *V. unguiculata* var. *biflora* (syn. Sub-sps: *catjang cylindrica*). *V. unguiculata* var. *sesquipedalis* in India is only of sporadic occurrence.

Crop improvement work to develop high-yielding, disease and pest resistant, short-duration varieties suitable for different cropping systems and agro-climatic conditions has yielded many varieties. A list of suitable varieties identified and released for different zones in India for cultivation are furnished in the Table 8.12.

Kharif Pulses

**Table 8.12** Improved cowpea varieties released for cultivation in different zones in India

Zone	Variety	Year of release	Area of adoption	Special character
North Western Zone (Punjab, Haryana, Western U.P., Rajasthan, H.P. and J&K)	Pusa Sawani (T 5269)	1952	Whole zone	-
	C 152	1978	Whole zone	Able to produce second flush
	T 2	1978	Whole zone	Dual purpose, fodder and green manuring
	RS 9	1980	Rajasthan	-
	JC 10	1980	Rajasthan	-
	Swarna (V 38)	1981	Whole zone	High protein
	UPC 8705	1996	Whole zone	All seasons
	Haryana lobia 88	1997	Haryana	Fodder type, YMR
	Pusa Sampada (V 585)	1999	Whole zone	Free from common diseases
	RC 101	2001	Rajasthan	Moderate disease tolerance
	Durga Kranti (RCV 7)	2001	Rajasthan	-
	UPC 607	2003	Whole zone	Shattering tolerant, YMR
	V 578 (Pusa 578)	2004	Delhi	YMR
	CL 367	2006	Punjab	-
	UPC 618	2006	Whole zone	Drought tolerant, YMR
	RCP 27 (FTC 27)	2006	Rajasthan	YMR, MPBR
	Kashi Kanchan (VRCP 4)	2008	Whole zone	Early type
	Pant Lobia 1	2008	Uttarakhand	-
	C 519 (Himachal Lobia 11)	2010	H.P.	-
	Hisar Cowpea 46 (HC 98-46)	2010	Haryana	Responsive to fertilizer
North Eastern Zone (Eastern U.P., Bihar,	Pusa Sawani (T 5269)	1952	Whole zone	-
	Gomti	1974	Bihar, Jharkhand	Summer
W.B., Odisha and Asom)	C 152	1978	Whole zone	Able to produce second flush
	T 2	1978	Whole zone	Dual purpose fodder and green manuring
	Cowpea 74	1978	Whole zone	-
	Bundel Lobia 2	1994	Whole zone	Fodder type

Table 8.12 contd



Table 8.12 concluded

Zone	Variety	Year of release	Area of adoption	Special character
Central Zone (M.P., Maharashtra and Gujarat)	Kashi Kanchan (VRCP 4)	2008	Whole zone	Early type
	Swama Harita	2008	Jharkhand	Early, YMR
	C 152	1978	Whole zone	Able to produce second flush
	GFC 2	1980	Gujarat	Fodder type
	No. 5-19-4-1	1982	Maharashtra	Suitable for black soil
	No 2-1	1982	Maharashtra	Suitable for black soil
	Gujarat Cowpea 1	1984	Gujarat	RKNR
	S 288	1985	Maharashtra	
	Gujarat Cowpea 2	1985	Gujarat	Drought tolerant
	DFC 1	1997	Maharashtra	Fodder type
South Zone (A.P., Karnataka, T.N. and Kerala)	Gujarat Cowpea 3	1990	Gujarat	-
	Gujarat Cowpea 4	1999	Gujarat	-
	UPC 9202	1999	Whole zone	Shattering tolerant
	Co 1	1970	Whole zone	Dual purpose for grain and fodder
	Lalitha	1976	Karnataka	Dual purpose for grain and fodder
	Co 2	1978	T.N.	
	C 152	1978	Whole zone	Able to produce second flush
	S 488	1980	Karnataka	
	JC 5	1980	Whole zone	
	Kankamani	1980	Kerala	Rabi, Summer
	KM 1	1982	T.N.	
	Co 4 (COVU 1)	1984	T.N.	RRT, WT,
	Krishna Mani (PTB 2)	1985	Kerala	-
	Palyur 1	1986	T.N.	-
	Vamban 1	1997	T.N.	-
	UPC 9202	1999	Whole zone	Shattering tolerant
	KBC 2	2001	Karnataka	
Co 6	2001	T.N.	RRT	
Subhra	2002	Kerala	Free from com- mon diseases	
Co (CP) 7	2005	T.N.	-	

H.P., Himachal Pradesh; J & K, Jammu and Kashmir; U.P., Uttar Pradesh; W.B., West Bengal; M.P., Madhya Pradesh; A.P., Andhra Pradesh; T.N., Tamil Nadu  
MPBR, *Macrophomina* blight resistant; RKNR, root-knot nematode resistant; RRT, root-rot tolerance; WT, wilt tolerant; YMR, yellow mosaic resistant

### Horsegram

Till recently it was considered as a member of genus *Dolichos*. Verdcourt (1982) regrouped it under a separate genus *Macrotyloma* and called it *Macrotyloma uniflorum*. Another species *Macrotyloma axillare* is a fodder type.

The systematic breeding programme for developing high-yielding varieties in horsegram began in late 1950's. and many good selections were identified. However, the high-yielding local cultivars were used for sowing in many areas. In recent years, many State Agricultural Universities (SAUs) have also started breeding work to develop high-yielding, disease- and pest resistant/tolerant varieties for different agro-climatic conditions. The important improved varieties available for cultivation have been listed in Table 8.13.

**Table 8.13** Improved horsegram varieties released for cultivation in different zones in India

Zone	Variety	Year of release	Area of adoption	Special character
Northern Hill Zone (Hills of H.P., J&K, Uttarakhand)	Bizu Kulthi (HPK 4)	1980	H.P.	-
	V.L. Gahat 1 (VLG 3)	1983	Uttarakhand	MPBR
	Deepali (HPK 6)	1988	H.P.	
	V.L. Gahat 8	2005	Uttarakhand	AR
	V.L. Gahat 10	2006	Whole zone	YMR, RRR.
	V.L. Gahat 15 (VLG 15)	2009	Whole zone	AR
	V.L. Gahat 19	2010	Whole zone	Resistant to many common diseases
North Eastern Zone (Central and Eastern U.P., Bihar, W.B., Asom)	Madhu	1978	Bihar	
	Birsa Kulthi 1 (Strain 43)	1985	Bihar	MPBR
North Western Zone (Delhi, Punjab, Western U.P., Northern Rajasthan, Haryana)	Maru Kulthi	1989	Rajasthan	
	Pratap Kulthi 1 (AK 1)	2005	Rajasthan	
Central Zone (M.P., Rajasthan, Maharashtra, Gujarat)	Dapoli 1	1986	Maharashtra	
	MAN	1989	All areas	
	Arija Kulthi 21 (AK 21)	1999	All zones	AR
South Zone (Odisha, A.P., Karnataka, T.N., Kerala)	Co 1	1953	T.N.	
	Hebbal Hurali 1	1976	Karnataka	All season
	Hebbal Hurali 2	1976	Karnataka	All season
	Palem 1	1998	A.P.	
	Palem 2	1998	A.P.	Rabi, YMR
	Paiyur 2	1999	T.N.	YMR
	PHG 9	2001	Karnataka	PMR, AR
	GPM 6	2009	Karnataka	Forage type

Table 8.13 contd



Table 13. *concluded*

Zone	Variety	Year of release	Area of adoption	Special character
	CRIDA 1-18R	2009	Whole zone	PMR, YMR, RRR
	CRIDA Latha (CRHG 4)	2010	Whole zone	PMR, YMR, RRR

H. P., Himachal Pradesh; J & K, Jammu and Kashmir; U.P., Uttar Pradesh; W.B., West Bengal; M.P., Madhya Pradesh; A.P., Andhra Pradesh; T.N., Tamil Nadu  
AR, Anthracnose resistant; MPBR, *Macrophomina* blight resistant; PMR, powdery mildew resistant; RRT, root-rot tolerant; YMR, yellow mosaic resistant

### Mothbean

Mothbean belongs to genus *Vigna*. Marechal *et al.* (1978) after detailed studies changed the previous name *Phaseolus aconitifolia* (Jacq.) to *Vigna aconitifolia* (Jacq.) Marechal. Another species *Vigna trilobata* (L.) is a semi wild species endemic to India. It is being used for fodder purpose.

The varietal development programme in mothbean has been limited over the years. The old T-3 is the fodder type identified in mothbean more than 60 years ago (Saini and Malik, 1947). Only the local cultivars have been used for sowing for many years. Recently some high-yielding, drought- and disease tolerant varieties have been identified and released for cultivation (Table 8.14). There are distinct maturity groups in mothbean, viz. early 60-65 days, medium 70-90 days and normal >90 days.

Table 8.14 Improved mothbean varieties released for cultivation in different states in India

Variety	Year of release	Area of adoption	Special character
Baleshwar 12	1960	Gujarat	
Type 1	1967	Uttar Pradesh	
GAU Moth 1	1978	Gujarat	
Jadia	1980	Rajasthan	
Jwala	1985	Rajasthan	
Moth 880	1989	Rajasthan, Maharashtra, Gujarat	
Rajasthan Moth 40	1994	Rajasthan	
IPCMO 912	1995	Rajasthan	
CAZRI Moth 1 (CZM 79)	1999	Rajasthan	
FMM 96	1999	Rajasthan	
Maru Vardhan (RMO 225)	1999	Rajasthan, Maharashtra	
Maru Bahar (RMO 435)	2002	Rajasthan, Gujarat, Maharashtra	Drought resistant YMR
RMO 423	2004	Rajasthan	
CAZRI Moth 3 (CZM 99)	2005	Rajasthan	
RMB 25 (RMO 2004)	2006	Rajasthan	
CAZRI Moth 2 (CZM 45)	2006	Rajasthan	
JMM 259 (Maru-Moth 1)	1988	Rajasthan	
Rajasthan Moth 257 (RMO 257)	2007	Rajasthan	YMR
TMV (Mb) 1	2007	Rajasthan	

YMR, Yellow mosaic resistance

## PLANT TYPES

### Pigeonpea

Pigeonpea is a perennial woody shrub mostly grown as annual for the seeds. Stem is strong and woody. Plants are freely branching and can grow up to 4 m tall. It has a very strong, profused and deep tap root extending up to 2 m below soil. Leaves are alternate, pinnately trifoliolate, stipulate, stipels small. Leaflets are lanceolate to elliptical, entire, acute apically and basally, penninerved, resinous on lower surface and pubescent. Leaves grow up to 15 cm long and 6 cm wide. Inflorescence will be in terminal or axillary racemes in the upper branches of the bush. Flowers are multi-coloured with yellow being predominant, red, purple, orange occur in streaks or fully cover the dorsal side of the flag. Flowers are zygomorphic and often cross (5-40%) pollinating in nature. Pods are compressed, bear 2-9 seeds and unshattering in nature after maturity. Seeds are lenticular to ovoid, measuring up to 8 mm in diameter and weigh about 10 seeds/gram. Seeds are separated from each other by slight depression in pod. Germination is cryptocotylor (hypogeal).

### Greengram

Greengram is erect or semi-erect, shrubby annual herb growing to a height of 30-120 cm. It is profusely branched with a tendency to twine at the tips. It possesses highly proliferated deep root system with the maximum root mass found in the first 30-cm depth. Leaves are alternate, trifoliolate and dark green with scattered hair on both sides on a long petiole. Flowers are pale yellow, crowded in axillary or terminal racemes in clusters of 10-25. Pod colour varies from black, grey to brownish and it measures 2.5-10 cm long and 4-6 mm wide. Each pod contains 10-20 globose or oblong seeds measuring 3.2-5.0 mm long and 3.0-3.8 mm wide. Seeds are usually green but may be olive, yellow, brown or purplish brown or marbled or mottled etc. The hilum of the seeds is flat and 1.3-1.7 mm long and 0.5-0.6 mm wide. It is narrowly obovate and margin slightly concave. Seed-coat surface is smooth or light coloured marked with fine crenulate lines. Micropyle is elevated with pore facing the hilum. The 100- seed weight varies from 1.5 to 4.0 g depending on variety. Greengram exhibits phanerocotylor (epigeal) type of germination.

### Blackgram

Like greengram, blackgram is an annual, semi-erect to spreading herb growing to a height of 25-90 cm. Stems are diffuse, branched, sometimes procumbent, and covered with long dense brown hairs. It possesses strong tap root system with many laterals. Leaves are trifoliolate, hairy with large ovate to lanceolate, entire leaflets. Flowers are pale yellow, 12-15 mm width, with a yellow spirally coiled keel. The flowers are borne in clusters of five to six on a short hairy peduncle in axillary racemes. Pods are short, erect to sub-erect, 4-7 cm long and 0.6 cm wide, brown to black, hairy, and with stout hooked beak, containing about 6-10 seeds. Seeds are small, oblong, cylindrical to ovoid oblong, slightly truncated at ends measuring 4.0-5.2 mm long and 3.5-4.1 mm



wide; averaging about 4 g/100 seeds with varying colour from black, dark brown to green. The testa is smooth and hilum white and concave. Germination is phanerocotylar (epigeal). Pods do not shatter readily. Flowers are self-fertile and self-pollinated. Flowering is indeterminate.

### **Cowpea**

Cowpea is an annual herb having erect or semi-erect or spreading habit. It can grow up to 80 cm or more tall. It has a very strong tap root system with profuse nodulation. The spread of the root system is large in upper portion and tapers towards underground. Stem is mostly procumbent often tinged with purple colour. The first leaves above cotyledons are simple and opposite but subsequent leaves are trifoliate and alternate. The terminal leaflet is often bigger and longer than the two asymmetrical laterals. Petioles are stout, grooved and measure 5-15 cm long. Leaflets are ovoid to rhombic in shape, may be entire or slightly lobed, with acute apex and measure about 6.5-16.0 cm long and 4-11 cm wide. Inflorescence is axillary with 2-4 flowers crowded near tips on short curved peduncles and measures about 2.5-15.0 cm long. Corolla may be dull white or yellow or violet in colour with standard petal measuring 2-3 cm diameter. Pods may be curved or straight or coiled. Seeds are 2-12 mm long globular to reniform, smooth or wrinkled. Colour varies from red, black, brown, green buff to white as dominant. Seeds may be fully coloured or spotted, marbled, speckled, eyed or blotched. The test weight varies 5 to 30 g/100 seed depending upon the variety. Germination is phanerocotylar (epigeal). Flowering depends on varietal sensitivity to local photoperiod and temperature condition.

### **Horsegram**

It is a short statured, slender, sub-erect, annual herb with slightly twining downy stems and branches. Plant height varies from 30 to 50 cm. Leaves are trifoliate, leaflets pilose, entire, membranous, broadly ovate, acute and measure about 2.5-5.0 cm long. Laterals oblique, stipules ovate-lanceolate and are about 1 cm long. Stipels are minute. Flowers are yellow or greenish, 1-3 on a very short, sessile or sub sessile, 2-4 flowered axillary racemes. It is self-pollinated crop. Pods are shortly stipulate, linear-oblong 2.5-6 cm long about 6 mm broad slightly curved, sessile smooth or tomentose, slightly hairy, 6-8 seeded and tipped with a persistent style 0.6 cm long. The seeds are ovoid, 5-8 seeds/pod, colour varies from pale fawn, light, red, brown or black. Sometimes they may be with faint mottles or with small scattered black spot, hilum central. Horsegram exhibits phanerocotylar (epigeal) mode of germination.

### **Mothbean**

Mothbean is an annual herbaceous plant having spreading and prostrate habit. It resembles a small mat as it is ground hugging type and grows to a height of about 30-45 cm. It possess deeply notched leaflets on long leaf branches. The terminal leaflet bears 5 acuminate lobes and lateral leaflet bears 4 lobes. Trailing primary branches number up to 12, measure 60-130 cm long and emerge from short erect main stem. Branches are hairy and are relatively



long. Inflorescence is axillary, flowers are small, yellow; pods are short measuring up to 5-7.6 cm, smooth, glabrous in nature. Each pod contain 4-9 seeds. Seeds are small, colour varies from light brown to dark reddish brown with white hilum. The root system is medium in depth and support *Rhizobium* nodules, proliferation depends on moisture status of soil and environmental conditions. Germination is phanerocotylor (epigeal).

### CLIMATE

The *kharif* pulses are grown in a wide variety of conditions and they are spread across diverse ecosystems at different altitudes and latitudes.

#### Pigeonpea

Pigeonpea is a highly drought-resistant crop. It can successfully grow in areas receiving only 65 cm annual rainfall, as the crop matures fast and pest damage is low. It is mostly photoperiodic sensitive and short days result in reduced vegetative phase and onset of flowering. Moist and humid conditions are conducive for vegetative growth. Average annual rainfall of 60-100 cm with moist conditions for the first 8-10 weeks and drier conditions during flowering and pod-development stage results in highly successful crop. However, rains during flowering result in poor pollination and pod development and also result in infestation of pod-borer. A temperature range of 18-27°C is desirable. However, there are varieties which can tolerate <10°C and >35°C.

#### Greengram

As there are both short day and long day varieties available, it can be grown successfully in almost all the seasons. However, it is mostly cultivated during summer and *kharif* seasons in northern India and in winter in peninsular India. It can tolerate high temperature up to 40°C but does well in temperature range of 30-35°C. It is drought resistant but susceptible to frost, water logging and salinity. Some varieties can, however, tolerate even alkalinity and salinity. A well-distributed 60-75 cm rainfall is highly suitable for better growth, but rains during flowering are detrimental as they affect pollination and fertilization. Persisting rains also result in decolouration of seeds and in some case infestation by fungus. A hot humid climate with sufficient soil moisture is ideally suitable for better performance of greengram.

#### Blackgram

As tropical crop, blackgram tolerates high temperatures. It is cultivated both in *kharif* and *rabi* seasons (Jeswani and Baldev, 1990). It is also cultivated in summer season in India. It is a short day plant, but day neutral cultivars are available for cultivation in the long days of summer. The optimum temperature for better growth ranges between 25 and 35°C, but it can tolerate up to 42°C. It is a hardy and drought resistant plant, and can be grown in areas receiving 650 mm rainfall or less. It is sensitive to cloudy weather and can not tolerate frost.

#### Cowpea

Cowpea is primarily a tropical crop. It can withstand considerable drought



and moderate amount of shade. It is relatively less tolerant to waterlogging. Some species exhibit indeterminate growth habit as long as the weather conditions are suitable. The determinate types produce taller plant, more flowers and subsequently higher grain yield if the growing period is long. It requires long day conditions for better growth and yield. Dry matter production and root development and nodulation are reduced if the photoperiod is <12 hours and 13 minutes. It tolerates heat but frost kills it. Cowpea tolerates relatively dry conditions and can be grown with less rainfall and under more adverse conditions. Variations in day temperature affect crop duration and yield. Marked cultivar differences in environmental response have also been identified.

### **Horsegram**

Horsegram is extremely drought-resistant crop. Moderately warm, dry climatic conditions are suitable for its optimum growth. It does not grow well on higher altitudes because of cool and wet climate. Horsegram can be cultivated up to an altitude of 1,000 m above the sea level. The temperature range of 25-30°C and relative humidity between 50 and 80% is optimum for its growth. Heavy rains during the initial stages of crop growth affect nodule formation owing to poor aeration in the soil. A well-distributed rainfall of about 800 mm is sufficient for its successful cultivation, but it performs well even under low rainfall areas.

### **Mothbean**

Mothbean is a hot weather, drought-resistant legume. It is grown in hot climates with 500-750 mm of annual rainfall. Even with as little as 50-60 mm rainfall as 3-4 showers during the growing period, a good yield can be obtained. It can tolerate high temperature range of 45°-50°C during vegetative growth.

## **SOILS**

Pigeonpea, greengram, blackgram and cowpea can be cultivated on variety of soils from sand to heavy clay loams. However, well-drained medium heavy loams are best suited. Cultivars tolerant to water-logging, frost and salinity are available in pigeonpea.

Horsegram can also be cultivated in a wide range of soils from light to heavy soils. It can be successfully grown in less fertile, deep red loams, black cotton soils, clayey paddy soils, heavy upland soils, and even newly cleaned forest soils. Alkaline soils are not suitable for this crop. Mothbean grows well on arid soils having low fertility.

## **SEEDBED PREPARATION AND SOWING**

### **Seedbed preparation**

The seedbed preparation is similar for all *kharif* pulses and number of tillage operations depend on soil type and climatic conditions. A fine seedbed with friable soil with optimum moisture condition is needed for better germination. Since most of the *kharif* pulses have epigeal germination, i.e. the cotyledons rise above ground before vegetative sprouting emergence, hardy, cloddy or crusty surface layer hinder the seedling emergence and affect proper



germination. Dry soil conditions and high soil resistance are the major soil physical constraints limiting greengram seedling emergence in clay soils (Cook *et al.*, 1995). It is therefore necessary to have soft, smooth, and fine seedbed.

The heavy soils need one pre-shower deep ploughing in summer followed by 2-3 cultivation and harrowing after early showers. In dryland areas, deep ploughing results in better moisture conservation, root proliferation and higher grain yield compared to shallow cultivation (Vadi *et al.*, 2006). The final tillage operation with one country plough followed by planking breaks the clods.

The light soil may be prepared by 2-3 good harrowing or cultivation followed by surface smoothing by planking. The land should be properly leveled and a good gradient should be maintained to allow proper movement of rainwater without any waterlogging.

If land is infested with perennial weeds, care should be taken to remove them along with their vegetative propagules before sowing of the crops. In areas known to be endemic to soil-borne pests and diseases, suitable preventive measures should be taken by way of soil incorporation of pesticides before sowing.

Some special observations on individual crops are given below.

**Pigeonpea:** In intensive cropping systems, planting of pigeonpea in broadbed and furrow with a provision of post-monsoon irrigation at 0.4 IW : CPE ratio improved the yield over flat planting and unirrigated pigeonpea.

**Greengram:** For summer crop, a pre-sowing irrigation and deep ploughing followed by 2-3 cultivations using harrow and land leveling will be sufficient. When crop is sown in post-monsoon season on residual moisture conditions, care should be taken to conserve moisture by way of minimum cultivation just to make a proper seeding condition at uniform depth.

**Blackgram:** When the sowing is done in the rice fallow, seeding can be done without cultivation. After the crop establishes, one or two intercultivations, check the evaporation losses of moisture and reduce the weed population. Intercultivations also aids in better root proliferation.

### Sowing time

**Pigeonpea:** The first fortnight of December for summer sowing at Kathalagere in Karnataka (Jayanna, 2001), first fortnight of July for *kharif* or rainy season sowing in Uttar Pradesh (Singh, 2006) and first fortnight of August for *rabi* or winter season sowing at Samastipur in Bihar (Anil Kumar *et al.*, 2005) has been found optimum time of sowing. However, slight variations in sowing dates have been reported by different workers for different regions.

**Greengram:** The *kharif* greengram is sown with the onset of monsoon during June-July. The optimum time of sowing varies from place to place, depending on the monsoon rains actually received. Sowing in the first fortnight of July has been reported to be optimum, as shown by the trials under AICRP on MULLaRP also revealed the similar trend at different places (Table 8.15). This time of sowing is more common in northern and eastern parts of the country. The *rabi* greengram is sown during the post monsoon period up to December. This is practiced in eastern and southern parts of the country, where the winters are not severe and the crop is grown after the harvest of *kharif* crops.



The summer crop is grown under irrigated conditions for which sowing is done during March. Sowing in the first week of March recorded the highest grain yield in Gujarat (Patel, 2003) as compared to the last week of March in eastern Uttar Pradesh (Ram and Dixit, 2001). Kumar *et al.* (2006) reported that at Hisar (Haryana) 15 February to 25 March is the best time of sowing for spring season, while for summer mungbean 10-15 April is the most suitable time.

**Blackgram:** Sowing between mid-June to mid-July is found to be optimum for the *kharif* season. The optimum time for summer crop is during March (Jaiswal, 1995). For spring season sowing in January was found to be optimum (Reddy *et al.*, 2007).

**Horsegram:** The time of sowing depends on the onset of monsoon. Often the timely onset of monsoon is used for other *kharif* season crops. Delay in sowing reduces yields (Table 8.16). The delayed onset of monsoon can also be used for horsegram sowing. The optimum time of sowing in general has

been first fortnight of June, but it can be taken up to August (Naik, 2001). In the *rabi* the time of sowing coincides with the harvest of *kharif* season crop and cessation of monsoon to make full use of the residual moisture. September first fortnight would be suitable for *rabi* sowing (Kalita *et al.*, 2003).

**Mothbean:** As mothbean is cultivated in scanty rainfall areas of western region, the time of sowing often depends on the rainfall. As the total rainfall in those areas is very small, sowing of crop as soon as the rains start is more important. In general, first fortnight of July has been observed to be optimum time of sowing.

### Quality seed

Quality seed is the basic input needed to ensure good crop stand and ultimately higher yield. In spite of development of number of improved varieties of different pulse crops, their availability and popularity among farmers is low due to lack of systematic seed production and distribution facility. Most of the time farmers are forced to use their own seeds, which at times are bereft of quality due to factors beyond the control of farmers. Lack of grading, poor storage facility and infestation with insect-pests and pathogens impairs the quality of seeds. The reduction in germination percentage often results in

**Table 8.15** Grain yield (kg/ha) of greengram as influenced by dates of sowing during *kharif*

Date of sowing	Location		
	Raipur	SK Nagar	Vamban
15 July	779	731	554
25 July	567	270	564
14 August	442	-	537
CD (P = 0.05)	23	161	23

Source : AICRP on MULLaRP (2008)

**Table 8.16** Grain yield (kg/ha) of blackgram as influenced by delayed planting in *kharif*

Sowing time	S.K. Nagar	Faizabad
25 July	446	646
9 August	373	580
24 August	184	453
CD (P=0.05)	56	62

Source: AICRP on MULLaRP (2007)

requirement of large seed rate or less crop plant population. Hence it is imperative to procure seeds of assured quality and genetic make up from reliable seed supplying agencies.

Seed treatment in pulse crops is an important practice to obtain higher yield. Three kinds of seed treatments are required as given below:

**Treatment with fungicides/insecticides:** The seed treatment with fungicides like captan, bavistin, brassicol or thiram @ 2.5 g/kg seed before sowing effectively controls fungi and reduces incidence of both seed and soil-borne diseases in the initial stages of crop growth. Further seed treatment with chemicals like carbofuran etc. reduces the infestation of termites, cutworms etc. usually found in light soils.

**Rhizobium inoculation:** *Rhizobium* inoculation with appropriate strains is essential for all legumes. Seed treatment with efficient strains of *Rhizobium* has been found to improve yields of pulses up to 50% over the untreated control (Table 8.17). The response to *Rhizobium* seed inoculation is more pronounced where pulses were earlier not grown in the same field. The appropriate strains for kharif pulses are given in Table 8.18.

**Table 8.17** Response of Kharif pulses to *Rhizobium* inoculation at different research centres in India

Crop/Location	Soil type	Grain yield (q/ha)		% Increase
		Control	Inoculated	
<b>Pigeonpea</b>				
Jabalpur	Vertisol	4.82	6.93	44
Ludhiana	Entisol	6.21	7.49	20
Hisar	Aridisol	19.85	18.87	10
Coimbatore	Alfisol	3.58	4.16	16
Hyderabad	Alfisol	11.30	16.52	46
<b>Greengram</b>				
Dholi	Entisol	4.48	6.78	51
Ludhiana	Entisol	7.97	10.02	26
Hisar	Aridisol	11.83	12.83	9
Madurai	Alfisol	11.47	15.12	32
Hyderabad	Alfisol	3.73	4.56	22
<b>Blackgram</b>				
Rahuri		9.06	9.42	4
Akola		6.98	7.54	7
Parbhani		7.20	7.33	2
Hisar		17.98	19.59	8
Masodha		7.82	8.46	8
<b>Cowpea</b>				
Hisar		11.32	13.87	18
Bichpuri		10.91	12.40	12
<b>Horsegram</b>				
South India*		403	618	29

Source: Katyal *et al.* (1994), Hegde and Dwivedi (1994), Singh and Ali (2001)

\*Mean of 6 locations



**Table 8.18** Efficient *Rhizobium* strains for different pulse crops

Crop	<i>Rhizobium</i> strain	Source of culture
Pigeonpea	IHP-195	ICRISAT, Hyderabad
	IC-3100	ICRISAT, Hyderabad
	CC-1	TNAU, Coimbatore
	A-2	GBPUAT, Pantnagar
	A-19	IARI, New Delhi
	UASB 722	UAS, Bengaluru
Greengram	GMBS-1	TNAU, Coimbatore
	M-10	IARI, New Delhi
	KM-1	CSAUAT, Kanpur
	MO-5	BHU, Varanasi
	MOR 1	-
Blackgram	BMBS-47	TNAU, Coimbatore
	DH-2	Durgapura, Rajasthan
	BDN-F	Badnapur, Maharashtra
	KU-1	CSAUAT, Kanpur
	Urad-10B	IARI, New Delhi
	BMBS 17	TNAU, Coimbatore
	UP 3	-
VRU	-	
Cowpea	Cowpea-109	IARI, New Delhi
	UAS-IV-5	UAS, Bengaluru
	TAL-169	UAS, Bengaluru
	DC-6	Navgaon, Rajasthan
	GMBS-1	TNAU, Coimbatore

Source: Kumar (1990); Khurana and Dudeja (1997); AICRP on MULLaRP (2006-07 and 2007-08)

**PSB inoculation:** Some heterotrophic bacteria and fungi have the ability to solubilize inorganic phosphorus from insoluble sources, such as, tricalcium phosphate, ferric aluminum and magnesium phosphate, rock phosphate and bone meal. Important phosphate-solubilizing bacteria (PSB) are : *Pseudomonas striata*, *Bacillus polymixa*, *Aspergillus awamori*, *Penicillium digitatum* etc. Inoculation of seeds or seedlings with microphos biofertilizers can provide 30 kg P<sub>2</sub>O<sub>5</sub>/ha equivalent of phosphorus applied as superphosphate (Gaur, 1990).

When seeds are treated with fungicides, a double dose of bacterial culture may be used. The fungicide treatment should be done first followed by bacterial cultures like *Rhizobium*, phosphorus solubilizers etc. The mercury based preparations of fungicides like ceresan are detrimental to *Rhizobia*. Hence, they should be used cautiously when *Rhizobium* treatment is contemplated.

#### Seed rate

**Pigeonpea:** In general, a seed rate of 8-10 kg/ha for longer duration, 10-12 kg/ha for medium duration (Ramakrishna *et al.*, 2005) and 12-15 kg/ha for short-duration varieties is sufficient in pigeonpea.

**Greengram:** A seed rate of 15-20 kg/ha for *kharif* and 25 kg/ha for summer or spring season has been recommended for greengram (Jeswani and Baldev,

1990). However, the increasing seed rate is found to have positive influence on the grain yield of greengram. Sekhon *et al.* (2006) reported that the optimum seed rate for higher productivity was 37.5 kg/ha for summer crop and 30 kg/ha for rainy season crop. A seed rate of up to 20 kg/ha was sufficient in many areas.

**Blackgram:** A seed rate of 12-15 kg/ha for *kharif* sowing and about 20-25 kg/ha for summer sowing would be optimum. A seed rate of up to 20 kg/ha recorded significantly higher grain yield as compared to lower rates.

**Cowpea:** In general, cowpea grown for grain purpose needs a seed rate of 25-30 kg/ha and for fodder it needs a higher seed rate of 40 kg/ha to have more plants per unit area.

**Horsegram:** A seed rate of 25-30 kg/ha is found optimum (Patra and Nayak, 2000; Kalita *et al.*, 2003).

**Mothbean:** A seed rate of 10-15 kg/ha has been found optimum for mothbean (Babu Ram *et al.*, 2007).

If pulses are raised in intercropping systems, the seed rate depends on the proportion of area available for them. In case of poor germination percentage of the seed and in suspected poor moisture conditions, a little higher seed rate may be required.

### Spacing

The optimum spacing depends on variety, season and planting system. Most of the short-duration varieties need narrower spacing while long-duration varieties having longer vegetative periods perform well under wider spacing. Further, planting pattern like paired row planting, strip planting and cropping season too influence the spacing. The crop sown during summer is poorly branched and ceases its vegetative growth early due to high temperatures. Thus it needs narrow spacing and higher plant population to offset the effect of reduced branching and hence yield. The crop grown during *kharif*, on the other hand, needs wider spacing and lower plant population as compared to summer sowing, mainly due to mild temperature and prolonged vegetative growth and profuse branching.

**Pigeonpea:** An inter-row spacing of 40-60 cm and an intra-row spacing of 10-15 cm has been found optimum for many short-duration varieties under varying agroclimatic conditions. In case of long-duration varieties, 60-120 cm inter-row and 10-20 cm intra-row spacing has been found suitable. In post-rainy season short-duration varieties, the spacing can be further reduced to 25 cm  $\times$  10 cm (Desai and Intwala, 1999).

**Greengram:** In general, an inter-row spacing of 25-30 cm and intra-row spacing of 5 cm is optimum for summer and *rabi* season greengram (Rajesh Kumar *et al.*, 2000; Sekhon *et al.*, 2006). The *kharif* crop needs a spacing of 30-45 cm between rows and 5-10 cm within rows (Patel *et al.*, 2005). At Hisar in Haryana, plant spacing of 20 cm  $\times$  10 cm was found adequate (Kumar *et al.*, 2006).

**Blackgram:** An inter-row spacing of 20-30 cm and intra-row spacing of 5-10 cm has been found to be optimum for summer and winter crop (Mendhe *et al.*, 2002). A wider spacing of 30-45 cm between rows and 5-10 cm within rows is optimum for *kharif* crop (Borah, 1994).



**Cowpea:** An inter-row spacing of 30-45 cm and intra-row spacing of 10-15 cm (Yadav 2003) is optimum for spreading types. The non-spreading types require an inter-row spacing of 30 cm and intra-row spacing of 5-10 cm (Pathan *et al.*, 2006).

**Horsegram:** A spacing of 25-30 between rows and about 5 cm between plants has been found optimum.

**Mothbean:** It requires a spacing of 30-45 cm between rows and 10-20 cm spacing between plants for good growth (Yadava and Beniwal, 2006). Appropriated spacing is also slightly modified by the genotypes based on their growth habits.

### Plant population

The growth habit, duration of crop growth and spacing determine the optimum plant population. The dense and long-duration varieties usually occupy more area and thus require wider spacing, while less spreading and short-duration varieties need closer spacing and hence higher plant population.

**Pigeonpea:** A plant population of 3 plants/m<sup>2</sup> was found optimum for high-yielding varieties of Maruti and PET 3-19 in central Karnataka (Antaravalli *et al.*, 2002). While Padmalatha and Rao (1997) reported 10-11 plants/m<sup>2</sup> to be optimum at Tirupathi and further increase resulted in reduced yield. The optimum plant density for different varietal groups of pigeonpea is furnished in Table 8.19.

**Table 8.19** Optimum plant density for different pigeonpea types

Varietal group	Optimum plant density (plants/ha)	Reference
Long duration	42 x 10 <sup>3</sup>	Kumar Rao <i>et al.</i> (1992)
Medium duration	166 x 10 <sup>3</sup>	Reddy <i>et al.</i> (1991)
Early duration	333 x 10 <sup>3</sup>	Rao (1994)
Hybrid	60 x 10 <sup>3</sup>	Sekhon <i>et al.</i> (1996)

**Greengram:** A plant population of 3.33-4.00 lakh/ha was found optimum (Sekhon *et al.*, 2002; Ravi Nandan and Deepak Kumar, 2005). Among the methods of planting, rectangular planting is better than square planting.

**Blackgram:** A plant population of 60-100 plants/m<sup>2</sup> during summer and a lesser population of 40 plants/m<sup>2</sup> during *kharif* is optimum (Budhar *et al.*, 1991; Tomar and Tiwari, 1991; Kumaran and Subramanian, 2001).

**Cowpea:** A plant population of 2.0-2.5 x 10<sup>5</sup>/ha for spreading types and 3 x 10<sup>5</sup>/ha for non-spreading types is optimum (Singh *et al.*, 1992). However, crop grown for fodder purpose needs higher seed rate and closer spacing with increased population.

**Horsegram:** Systematic evaluation of plant populations for higher yield in horsegram and mothbean has not been reported so far. However, Keshava *et al.* (2006) reported that a plant population of 4.44 lakh/ha was ideal for horsegram in Karnataka.

## Kharif Pulses

### NUTRIENT MANAGEMENT

Nutrient management in pulse crops needs a careful consideration, as these crops possess deep tap root system and thus are capable of drawing nutrients from deeper layers from the soil. In addition, there are many bacterial and fungal cultures which are helpful in enhancing the biological nitrogen fixation (BNF), solubilize and mobilize the phosphorus in the soil. Although it is said that pulses are less exhaustive, their uptake is quite sizeable (Table 8.20).

**Table 8.20** N, P and K uptake by *kharif* pulses

Crop	Yield (tonnes/ha)	Place	N	P	K	Source
Pigeonpea	1.20	Ludhiana	85	5	16	Aulakh <i>et al.</i> (1985)
	1.80	Bengaluru	123	17	163	Maheswarappa <i>et al.</i> (1994)
Greengram	1.00	Ludhiana	100	21	61	Aulakh <i>et al.</i> (1985)
	0.69	Dholi	25	7	23	Singh <i>et al.</i> (1993)
Blackgram	0.73	Dholi	27	7	24	Singh <i>et al.</i> (1993)
Cowpea	1.66	Rahuri	109	32	76	Jadhav <i>et al.</i> (1994)
Horsegram	-	Tirupati	85	8	35	Annapumamma <i>et al.</i> (1989)

#### Pigeonpea

Chand and Vij (1991) have developed a fertilizer ready reckoner for pigeonpea and greengram (Table 8.21).

**Table 8. 21** Ready reckoner for fertilizer recommendation based on soil test for specific yield goals of pigeonpea and greengram

Soil test value (kg/ha)	Crop yield target (q/ha)			
	Pigeonpea		Greengram	
	10	15	10	15
<b>Alkaline <math>KMnO_4</math> oxidizable N</b>				
	<i>Fertilizer N (kg/ha) requirement</i>			
50	16	33	27	61
75	8	25	8	41
100	0	17	0	21
<b>0.5 M <math>NaHCO_3</math> extractable P</b>				
	<i>Fertilizer <math>P_2O_5</math> (kg/ha) requirement</i>			
10	31	63	47	92
15	15	47	25	70
20	0	31	3	48
25	0	15	0	25
<b>Normal ammonium acetate-extractable K</b>				
	<i>Fertilizer <math>K_2O</math> (kg/ha) requirement</i>			
75	22	45	30	60
100	13	37	20	50
125	5	28	10	40
150	0	20	0	30

Source: Chand and Viz (1991)



The inbuilt mechanism of biological nitrogen fixation enables pulse crops to meet 80-90% of their N requirements, hence a small dose of 15-25 kg N/ha applied at sowing is sufficient to meet the requirement of most of the pulse crops (Karwasra and Anil Kumar, 2007). Top-dressing of nitrogenous fertilizers has been found to mitigate the effect of waterlogging on the growth and yield ability of pigeonpea (Matsunaga *et al.*, 1994).

On an average, application of 60-80 kg P<sub>2</sub>O<sub>5</sub>/ha has been found optimum. The dose may, however, vary with the soil type (Table 8.22). Further conjunctive use of phosphorus with phosphorus solubilizers may reduce the phosphorus dose. Phosphorus applied to preceding crops may also affect the rate of phosphorus application in pigeonpea. In pigeonpea-wheat and rice-pigeonpea cropping systems, phosphorus applied to wheat and rice may meet the need of P in succeeding pigeonpea to a large extent and in some cases no application of P was required (Pasricha *et al.*, 1995; Reddy *et al.*, 1994). Likewise, the rate of phosphorus applied to pigeonpea may also be reduced in the succeeding crops (Shivran and Ahlawat, 2000).

**Table 8.22** Response of pulse crops to P fertilization

Crop/location	Soil	Response level of P (kg P <sub>2</sub> O <sub>5</sub> /ha)	Yield response (kg/ha)	kg seed/kg P <sub>2</sub> O <sub>5</sub>
<i>Pigeonpea</i>				
Hisar	Inceptisol	80	370	4.6
Bhopal	Vertisol	90	110	1.2
Ranchi	Alfisol (Low P-fixing soil)	60	590	9.8
Kalyani	Alfisol (High P-fixing soil)	105	410	3.9
<i>Greengram</i>				
New Delhi	Inceptisol	60	130	8.2
Kanpur	Inceptisol	30	14	4.7
Faizabad	Inceptisol	60	132	2.2
Jorhat	Alfisol	40	200	5.0
<i>Blackgram</i>				
Palampur	-	30	220	7.3
Gurdaspur	Entisol	90	820	9.1
Kanpur	Inceptisol	60	450	7.5
Pantnagar	Histosol	30	150	5.0

Source: Ganeshmurty *et al.* (2002)

Karwasra and Anil Kumar (2007) reported significant increase in grain yield of pigeonpea due to potassium application at 20 kg/ha under lower nitrogen and phosphorus application indicating that there must be some complementary effect of potassium.

In soils having low pH, application of calcium improves its availability to the growing plants. Application of sulphur increases the grain yield of pigeonpea (Palsaniya and Ahlawat, 2007). On the basis of mean yield data of 5 locations, it was found that pigeonpea responds to 20 kg S/ha (Table 8.23). Application of boron and zinc has also been found to influence the performance of

**Table 8.23 Seed yield of pulses**

S (kg/ha)	Location			S.E.M.	D.F.	P-value
	Bengaluru	Varanasi	Dhol.			
0	1,206	1,568	1,457	1.1	54	NS
20	1,331	1,907	1,500	1.462	51	NS
40	1,403	1,946	1,670	1.456	54	NS
CD (P = 0.05)	122	117	173	146	NS	NS

Source: AICPIP (1995-96); IIPR (1997-98)

**Table 8.24 Response of kharif pulses to micronutrients**

Micronutrient	Crop	Response (kg grain/ha)	
		Range	Average
Boron	Pigeonpea	30-320	100
	Blackgram	40-350	170
Iron	Blackgram	160-500	340
	Pigeonpea	-	160
Zinc	Blackgram	110-1,120	240
	Greengram	60-300	170
	Cowpea	-	210

Source: Singh (2001)

pigeonpea (Table 8.24). This is more so in alkaline soils where the zinc deficiency is usually noticed. Puste and Jana (1988) concluded that application of 25 kg zinc sulphate/ha resulted in economically higher returns. An application of 25 kg ZnSO<sub>4</sub>/ha increased the grain yield by 8.7% over control in the trials conducted under AICPIP (1990-91).

### Greengram

Application of 10-20 kg N/ha through fertilizer as a starter dose is usually adequate (Patel *et al.*, 2003a). Higher nitrogen doses tend to suppress nodulation, and do not increase seed yields except in the absence of effective nodulation. In greengram, grown with no-N fertilizer, N fixation started 12 days after sowing (DAS), increased rapidly 34 DAS (flowering) to reach a peak 45 DAS, had a secondary peak 60 DAS and then decreased until the plants died (83 DAS). With N fertilizer, N fixation started 14 DAS, increased slowly to reach a much lower peak 50 DAS and then decreased. Nodulation was greatly decreased by applied N, but N fixation per unit nodule weight was similar in both the cases. Cultivars in which %Ndfa (N derived from applied fertilizer) at flowering was <30% produced more shoot growth at later growth stages. It was suggested that these cultivars might respond more to applied N than high-fixing cultivars (Murakami *et al.*, 1991).

The most economic phosphorus application rates have been of the order of 40 kg P<sub>2</sub>O<sub>5</sub>/ha; however, linear yield responses up to 60 kg (Satish Kumar *et al.*, 2003) have been reported. Though superphosphate was found to be a better source of phosphorus, the use of rock phosphate, coupled with phosphate-solubilizing bacteria (PSB), recorded satisfactory yield (Singh *et al.*, 2006).



Limited information is available on the potassium fertilization in greengram. Nita Chanda *et al.* (2002) recorded positive response to levels of potassium in terms of leaf-area index, seed yield, protein yield, harvest index and net production value. Seed yield of spring greengram was increased significantly with the application of 10 kg N, 30 kg P<sub>2</sub>O<sub>5</sub>, 20 kg K<sub>2</sub>O, 20 kg S/ha along with *Rhizobium* compared to all other treatments in isolation and other combinations. Application of 20-40 kg S/ha is considered to be sufficient for both greengram and blackgram in AICPIP experiments (Table 8.25). Inclusion of micronutrients in fertilizer schedule is also found to influence the grain yield of greengram. Application of multi-micronutrients and zinc resulted in 39 and 34% higher grain yield, respectively, over no micronutrient.

**Table 8.25** Seed yield of greengram and blackgram as influenced by sulphur

S (kg/ha)	Greengram		Blackgram	
	Ludhiana	Samba	Varanasi	Kanke
0	919	591	650	490
20	1,090	773	815	650
40	1,081	650	855	710
CD (P = 0.05)	114	64	124	35

Source: AICPIP (1994-95)

#### Blackgram

A starter dose of 15-20 kg N/ha applied at the time of sowing results in better initial growth and development (Yakadri and Murthy, 2006). The combined application of N and P further increased seed yield compared with individual application. The seed inoculation with appropriate *Rhizobium*, plant growth-promoting rhizobia (PGPR) culture along with phosphate solubilizing bacteria (PSB) also increases seed yield and uptake of nutrients (Gunasekaran *et al.*, 2004). Under rainfed conditions applications of 2% urea spray 30, 40 and 60 days after sowing recorded positive response in blackgram (Reddy *et al.*, 2005).

A dose of up to 40-60 kg P<sub>2</sub>O<sub>5</sub>/ha has been found optimum (Patel and Thakur, 2003) in different locations. Blackgram recorded positive response to application of potassium up to 30 kg/ha both under irrigated and unirrigated condition (Sarkar and Pal, 2003). Further, application of potassium along with nitrogen and phosphorus recorded positive response because of complementary effect of nutrients. Application of sulphur (Table 8.25) and molybdenum alone or in combination significantly increased the vegetative growth, nodule numbers and yield of blackgram (Singh *et al.*, 2006).

#### Cowpea

Application of 20-30 kg N/ha was found optimum to get better response in cowpea at Hyderabad under rainfed conditions (Mishra and Baboo, 2002). *Rhizobium* inoculation also influences growth and yield of cowpea. Hence seed inoculation with appropriate strains of *Rhizobium* culture reduces demand for nitrogenous fertilizers. The seed inoculation with *Rhizobium* along with 20 kg N/ha was observed to record higher growth and yield of cowpea (Baboo and Mishra,

2004). Application of 40-60 kg  $P_2O_5$ /ha has been observed to be optimum in most of the areas (Patel *et al.*, 2003b). In general a dose of 40-60 kg  $K_2O$ /ha is sufficient. Application of sulphur where the soil status is medium to low, brings about better nodulation and in-turn better growth and yield of the crop. Sharma and Jat (2003) recorded positive effect of sulphur up to 80 kg/ha.

### Horsegram

Application of 20 kg N and 17.5 kg P/ha increased seed yield by 51.5 and 31.6% over no N and no P, respectively, in Odisha (Patra and Nayak, 2000). Keshava *et al.* (2007) observed that application of 30 kg  $P_2O_5$ /ha was sufficient in Karnataka. The potassium, sulphur and micronutrient requirement is yet to be studied in detail.

### Mothbean

Yadava and Beniwal (2006) and Babu Ram *et al.* (2008) reported that application of 10-20 kg nitrogen and 40 kg  $P_2O_5$ /ha were sufficient for this crop in Rajasthan conditions. Singh and Sharma (2005) observed that application of zinc up to 8 kg/ha and thiourea (500 ppm) seed soaking and foliar spray improved the growth and yield of mothbean at Bikaner.

## WATER MANAGEMENT

In general, all the *kharif* pulses are grown without irrigation, and often require proper drainage to remove excess water from the field, as these are very sensitive to waterlogging (Sharma *et al.*, 2005). The *kharif* pulses do respond to irrigation when there is a long dry spell particularly during the critical stages of crop growth. The response of these crops to irrigation under different agro-climatic conditions is given in Table 8.26. The crops grown during spring/summer and winter do require irrigation when the soil moisture becomes limiting. The number and depth of irrigation varies with location and edaphic factors.

**Table 8.26** Grain yield, number of irrigations, irrigation water requirement, optimum IW : CPE ratio of *kharif* pulses

Crop/Location	Soil type	Grain yield (tonnes/ha)	No. Irrigations (depth, cm)	Irrigation water requirement (cm)	Optimum IW : CPE ratio
Pigeonpea ( <i>Kharif</i> ) Morena (Madhya Pradesh)	Sandy loam	2.00	3(7.5)	22.5	0.90
Kota (Rajasthan)	Clay	1.45	4(6)	24.0	0.75/0.80
Navasari (Gujarat)	Clay	2.05	2(8)	16.3	0.60
Rahuri (Maharashtra)	Clay	4.35	6(7)	42.0	0.75/0.80
Greengram (Summer) Pantnagar (Uttarakhand)	Silt clayloam	1.42	5(6)	30.0	0.60

Table 8.26 contd



Table 8.26 concluded

Crop/Location	Soil type	Grain yield (tonnes/ha)	No. Irrigations (depth, cm)	Irrigation water requirement (cm)	Optimum IW : CPE ratio
Bhavanisagar (Tamil Nadu)	Silt loam	1.32	5-6(4)	22.0	0.60
Greengram ( <i>Kharif</i> ) Dharwad (Karnataka)	Clay	1.32	1(6)	6.0	0.60
Blackgram (Summer) Bhavanisagar (Tamil Nadu)	Sandy loam	1.14	4(9)	30.0	0.60
Blackgram ( <i>Rabi</i> ) Chalakudy (Kerala)	Silty loam	0.65	5(3)	36.0	0.75

Source : Yadav *et al.* (2000)

### Pigeonpea

Branching, flowering and pod filling are the critical stages where moisture stress causes adverse effect on growth and development of the crop. Avoiding moisture stress at these stages results in higher productivity of the crop (IIPR, 1997-98) (Table 8.27).

In short-duration pigeonpea, 2 irrigations at flower irrigation and pod filling or irrigation at 80 mm CPE (140 mm water) proved equally effective in enhancing the productivity of the crop (Bhan, 1975). Rana and Malhotra (1992) observed that first irrigation 2 weeks after sowing and subsequent irrigations at CPE of 100 mm recorded the highest yield. In a study during *kharif* at Hyderabad, stress-free pigeonpea, on an average, recorded 68% additional seed yield compared to rainfed environment. Supplemental irrigation of 5 cm at early (vegetative), mid (flowering) and terminal (pod formation) period showed 31, 42 and 49% increase in seed yield, respectively, over rainfed crop (Reddy *et al.*, 2006).

Irrigation also determines the rooting pattern of the crop. The roots of crop irrigated at 0.4 IW : CPE ratio penetrated deeper than the crop irrigated at 0.6 IW : CPE ratio (Dixit *et al.*, 1997). Kantwa *et al.* (2005) reported that the bed and furrow planting and post-monsoon irrigation at 0.4 IW : CPE ratio improved pods/plant and seeds/pod of pigeonpea over flat planting and unirrigated pigeonpea, leading to similar increase in grain yield of pigeonpea by 10% in New Delhi.

As regards *rabi* pigeonpea, variety BDN 2 was studied for water requirement with three IW : CPE ratios: 0 (control), 0.30 and 0.60. Ascending irrigation levels progressively increased the grain yield without altering the

Table 8.27 Effect of soil-moisture stress on grain yield of pigeonpea

Treatment	Yield (kg/ha)
Stress throughout	2,005
No stress at branching	2,422
No stress at flowering	2,468
No stress at podding	2,429
No stress throughout	2,943
CD (P = 0.05)	342

Source: IIPR (1997-98)



harvest index, but the significant increase occurred only up to 0.30 IW : CPE ratio in Gujarat. The increase in grain yield over the control was 128% and 136% under 0.30 and 0.60 IW : CPE ratios respectively. The consumptive use of water increased with ascending irrigation levels, reaching as high as 323.50 mm under 0.60 IW : CPE ratio (Gajera and Ahlawat, 2006). In another study, Reddy *et al.* (2008) recorded higher seed yield, water-use efficiency and net returns up to 0.9 IW : CPE ratio in *rabi* pigeonpea in Hyderabad (Table 8.28).

**Table 8.28** Effect of irrigation schedules on water use efficiency (WUE), yield and net returns in *rabi* pigeonpea

Irrigation schedule	Seed yield (kg/ha)	WUE (kg/ha-mm)	Net returns (₹/ha)
Irrigation at critical stages viz. pre-flowering & pod filling	1,470	12.3	22,520
0.3 IW : CPE ratio	1,359	22.7	20,744
0.6 IW : CPE ratio	1,593	8.9	29,486
0.9 IW : CPE ratio	1,729	5.8	26,604
CD (P = 0.05)	175	-	-

Source: Reddy *et al.* (2008)

### Greengram

Only summer greengram needs irrigation. One pre-sowing irrigation for land preparation and 3-4 irrigations after germination are necessary to raise a good summer crop. However, timing, depth and number of irrigation depend on variety, and agro-climatic conditions. At Hisar in Haryana, the highest seed yield of greengram was recorded with three irrigations, one each at 20, 35, and 50 DAS in summer greengram (Kumar *et al.*, 2002).

Irrigation with 6 cm water per irrigation at 0.6 IW:CPE ratio corresponding to 2-3 irrigations including a pre-sowing irrigation gave the highest yield compared with IW : CPE ratios of 0.8 or 0.4, and one pre-sowing irrigation and irrigation 30 days after sowing or 30 and 45 DAS in a summer sown greengram (Prasad and Yadav, 1990). Singh and Idnani (2007) reported that the highest consumptive use and water use efficiency were recorded with furrow planting and irrigation method.

### Blackgram

*Kharif* blackgram is not irrigated. However, in summer, irrigation is necessary to save the crop from soil-moisture stress and high temperatures. The time and number of irrigation depend on the soil-moisture conditions and duration of the variety. In all 4-5 irrigations at an interval of 10-15 days may be required in most of the areas. Pod filling is the most important critical stage in terms of moisture stress. Irrigation at IW : CPE ratio of 0.6-0.9 recorded higher yield in summer blackgram at Palampur (Himachal Pradesh) (Chakor and Rana, 1992), and Faizabad (Uttar Pradesh) (Prasad and Yadav, 1990). In South Gujarat, application of irrigation at IW : CPE ratio of 0.9 recorded the highest seed yield, haulm yield, the highest contents of N and P in seeds and the consumptive use of water (CUW) (Patel *et al.*, 2005).



As regards *rabi* blackgram in Tamil Nadu, higher yield of blackgram was obtained by applying 40 mm water/irrigation at IW:CPE ratio of 0.5 (Jayraj, 1987). However, Manu and Wahab (2002a,b) observed that 3 irrigations given at vegetative, flowering and pod filling stages produced more nodules per plant, recorded the highest nutrient uptake, yield and returns per rupee invested in irrigation.

As regards rice fallows, the residual moisture is usually adequate to get a good crop of blackgram.

### **Cowpea**

The crop grown in summer needs frequent irrigations to tide over soil-moisture stress. The number, depth and frequency of irrigation depend on soil type and crop duration. Application of irrigations at critical stages of crop growth, viz. flowering and pod filling is essential for higher yield of crop (Sawant *et al.*, 1992). Irrigation at 75% available soil moisture in top 30 cm soil was found beneficial to achieve higher yield (Ahlawat *et al.*, 1978). Irrigation at an IW : CPE ratio of 1.0 recorded significantly higher seed and haulm yields in Gujarat (Patel *et al.*, 2008). Varietal differences in the response to irrigation were observed by Anitha *et al.* (2003a). They observed that, in general, irrigation at 0.8 IW : CPE recorded significantly higher water use efficiency, and among 8 cowpea cultivars (C 152, Kanakamani, Krishnamani, V 16, V 240, GC 3, V 118 and Pusa Phalguni), Kanakamani was the best cultivar, recording the highest yield followed by GC 3, V 240 and Krishnamani.

### **Horsegram and mothbean**

As both horsegram and mothbean are cultivated by resource poor farmers under dryland and rainfed conditions there has been no work on the irrigation requirement of these crops.

## **WEED MANAGEMENT**

### **Pigeonpea**

A large number of weeds emerge in pigeonpea fields. Important broad-leaved weeds are *Amaranthus viridis*, *Commelina benghalensis*, *Phyllanthus niruri*, *Euphorbia hirta* and *Digera arvensis*, while the most common sedges and grassy weeds are *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Setaria glauca*, *Digitaria sanguinalis* and *Echinochola* sp. The grassy weeds cause the greatest potential damage, closely followed by sedges. Besides directly competing with the crop, the weeds also harbor many pest and pathogens of pigeonpea.

Since pigeonpea is a slow-growing crop in the initial period, the first 7-8 weeks after sowing have critical crop-weed competition. Once the crop establishes and attains branching stage, it can compete with weeds and suppresses them effectively. The relative improvement in crop yield from weed management was 31% as against 5% due to fertilizer use (Ali, 1991). Intercultivation or hand weeding depending on the intensity of weed infestation at about 3-4 weeks after sowing is required. Pre-emergence application of



pendimethalin @ 0.9 kg/ha (Sukhadia *et al.*, 2000), alachlor @ 2 kg/ha (Rajput and Pandey, 1994; AICPIP, 1994-95) (Table 8.29) or pre-plant incorporation of fluchloralin @ 0.75–1.0 kg/ha (Das, 2008) have also been found to be highly effective in controlling weeds in pigeonpea. The combination of pendimethalin + one hand-weeding was observed to be the best method (Singh, 2007) in Uttar Pradesh. Other herbicides recommended for weed control in pigeonpea are imazethapyr @ 0.05 kg/ha and fenoxypop p-ethyl @ 0.05 kg/ha. Integrated weed management is the best approach to control weeds in pigeonpea.

**Table 8.29** Grain yield (kg/ha) of pigeonpea as influenced by weed-management practices

Treatment	Location					
	Coimbatore	Gulberga	Hisar	Kanke	Thrissur	Pudukottai
1. Unweeded check	255	556	908	630	1,075	294
2. Weed free check	738	800	1,403	1,720	2,141	942
3. Stale seedbed	686	755	1,020	810	1,363	848
4. 1 HW 25 DAS	417	600	1,056	1,050	1,380	386
5. 2 HW 25 and 50 DAS	673	778	1,270	1,380	2,006	767
6. Pendimethalin @ 1.0 kg/ha	469	711	1,230	980	1,663	441
7. Pendimethalin @ 1.5 kg/ha	534	767	1,208	860	1,803	537
8. Alachlor @ 1.0 kg/ha	490	755	1,190	840		493
9. Alachlor @ 2.0 kg/ha	527	633	1,347	970		580
10. Treatment 4+6	680	811	1,313	1,530	1,958	447
11. Treatment 4+8	653	722	1,303	1,140		755
12. Treatment 6+8	563	556	1,243	960		649
CD (P = 0.05)	18	98	121	94	202	32

Source: AICPIP (1994-95); DAS, days of the sowing

### Greengram

The composition of weed flora in greengram depends on the season, cropping system, soil type and land preparation. *Dactyloctenium aegyptium*, *Eragrostis riparia* and *Eragrostis pilosa*, *Trianthema portulacastrum*, *Echinochloa colonum* etc., are some of the major weeds noticed in greengram. The problem of weed competition is more severe in *kharif* season than in other seasons. Greengram is more sensitive to weed competition in the first 4-5 weeks after emergence due to early slow growth and establishment.

The higher plant population, starter dose of fertilizers and good seedbed preparation favouring good growth in the beginning reduces the weed competition to crop. Two hand-weedings at 20 and 40 days after sowing recorded better weed control and the highest grain yield of greengram at many locations (Table 8.30). Further one inter-cultivation at about 25-30 days too is helpful in minimizing weed problem. Pre-emergence application of pendimethalin or fluchloralin at 1.0 kg/ha + one hand-weeding at 20-30 DAS was the most effective method of weed control and resulted in the highest seed yield (Raman and Krishnamoorthy, 2005; Kumar *et al.*, 2005). Other herbicides



recommended are trifluralin (pre-plant) @ 1.5 kg/ha or trifluralin @ 0.75-1.0 kg/ha + fluazifop - *p*-butyl @ 0.5 kg/ha (20 DAS). Recommendations of herbicides may vary in different situations owing to weed population, environmental conditions and crop rotations etc.

**Table 8.30** Weed management in greengram and blackgram

Treatment	Greengram		Blackgram		
	Varanasi	Kota	Coimbatore	Srinagar	Kota
Weedy check	607	450	135	497	432
Hand-weeding at 20 and 40 DAS	865	778	692	837	906
Pendimethalin @ 1 kg/ha	772	633	646	585	793
Quizalofop-p-ethyl @ 37.5 g/ha as POE	708	588	392	701	737
Chlorimuron-ethyl @ 4 g/ha as POE	721	485	412	668	525
Fenoxypop-ethyl @ 5 g/ha as POE	736	614	378	589	715
Quizalofop-ethyl @ 37.5 g/ha as POE + Chlorimuron-ethyl @ 6 g/ha as POE	729	601	613	723	637
Fenoxypopethyl @ 5 g/ha as POE + Chlorimuron-ethyl @ 6 g/ha as POE	761	564	625	697	633
Imazethapyr @ 25 ml/ha as POE	765	665	528	714	670
CD (P = 0.05)	42	99	91	116	84

Source: AICRP on MULLaRP (2008 and 2009); DAS, days after sowing

### Blackgram

Major weeds in blackgram are: *Echinochloa colonum*, *Digitaria sanguinalis*, *Trianthema portulacastrum*, *Amaranthus viridis*, *Cyperus rotundus*, *Commelina benghalensis*, *Setaria glauca* (*S. pumila*), *Corchorus* spp., *Digera muricata*, *Acalypha indica*, *Portulaca oleracea*, *Cynodon dactylon*, *Phyllanthus niruri*, *Dactyloctenium aegyptium*, *Eclipta alba*, *Ageratum conyzoides*, *Celosia argentea*, *Euphorbia hirta*, *Panicum* spp., *Achyranthes aspera*, *Xanthium strumarium*, *Cleome* spp., *Croton bonplandianum* (*Croton sparciflorum*), *Merremia emarginata*. The first 10-40 days after sowing are critical for crop weed competition (Arun Kumar and Tewari, 2004). The extent of damage due to weeds can be as high as 50-60%.

Pre-emergence application of pendimethalin or fluchloralin or metolachlor or alachlor @ 1.5 kg/ha is effective in controlling weeds in blackgram (Reddy *et al.*, 2000; Shaik *et al.*, 2002; Randhawa *et al.*, 2002). Kumar (2000) reported that the pre-emergence application of fluchloralin at 1.5 kg a.i./ha also controlled *Cuscuta* effectively. Integrated weed management, i.e. pendimethalin or fluchloralin, followed by one hand weeding or weeder at 35 days after is the best for weed control in blackgram (Vaishya *et al.*, 2003). Post emergence application of sethoxydim @ 1 kg/ha 10 days after sowing has also been found to control weeds effectively in blackgram (Ramamoorthy *et al.*, 1994).



### Cowpea

The important weed flora observed in cowpea include *Eleusine indica*, *Eragrostis pilosa*, *Boerhavia diffusa*, *Achyranthes aspera*, *Borreria* spp., *Digitaria* spp., *Echinochloa colonum*, *Tridax procumbens*, *Commelina benghalensis*, *Rottboellia cochinchinensis*, *Cyperus rotundus*, *Cynodon dactylon*, *Amaranthus* spp., *Celosia argentea*, *Crotalaria* spp., *Dactyloctenium aegyptium*, *Gnaphalium indicum*, *Echinochloa crus-galli*, *Sorghum halepense* etc. (Singh and Prasad, 1987). The critical period of weed competition in cowpea is up to 45 days after emergence of the crop (Tripathi and Singh, 2001). Cultural practices like clean cultivation, use of weed seed free seeds, optimum plant population etc. reduce the weed problem to a great extent. Application of pendimethalin (0.45 or 0.60 kg/ha) or fluchloralin (0.45 or 67.5 kg/ha) as pre-emergence + hand-weeding at 30 DAS results in significant reduction in weed population and weed dry matter, and significant increase in crop yield (Parasuraman, 2000). Integrated weed control involving pre-emergence application of pendimethalin at 0.75 kg/ha + hand-weeding at 5 weeks after sowing recorded higher grain yield and net return in rainy- season cowpea (Patel *et al.*, 2003c).

### Horsegram

Weed studies are limited in horsegram. Very little information is available on the weed flora, critical crop weed competition period and weed control methods in horsegram in different agro-climatic conditions. Patra and Nayak (2000) reported that one hand-weeding 25 days after sowing increased seed yield by 12.2% over no-weeding. In a study in Kerala in field infested with *Cleome aculata*, *Euphorbia hirta*, *Alternanthera* sp., *Ageratum conyzoides*, *Phyllanthus niruri*, *Ischaemum rugosum*, *Panicum repens* and *Cyperus* spp., application of pretilachlor + hoeing 20 days after sowing resulted in the lowest total dry weight of weeds, highest seed yield, net returns and benefit : cost ratio in *rabi* horsegram (Anitha *et al.*, 2003b).

### Mothbean

Mothbean also experiences the competition of several weeds during its early growing period. Lack of appropriate land preparation and other agronomic practices aggravate the weed problem in mothbean. Shekhawat *et al.* (2003) reported that *Amaranthus spinosus*, *A. viridis*, *Cyperus rotundus*, *Tribulus terrestris*, *Cenchrus biflorus*, *Euphorbia hirta* and *Convolvulus arvensis* were the dominant weeds observed under Rajasthan conditions. They observed that application of fluchloralin up to 1.0 kg/ha recorded decrease in weed density and their dry weight and an increase in grain yield and net returns. In another study, application of fluchloralin at 1.00 kg/ha with one hand-weeding 30 DAS was at par with weed-free treatment (Bather *et al.*, 2005).

## INSECT-PESTS AND THEIR CONTROL

Pulses are prone to many insect-pests and diseases. They cause considerable damage if proper control measures are not taken. The losses in yield due to lack



of plant-protection measures vary from 50 to 100 % depending on the crop and varieties. Out of an array of insects attacking these crops, pulse borer (*Helicoverpa armigera*), pod bug (*Clavigralla gibbosa*), pod fly (*Melanagromyza obtusa*), blister beetle (*Mylabris* spp.), hairy caterpillars (*Spilosoma cajetani* and *Amsacta moorei*), cutworms (*Agrotis ipsilon* and *Ochropleura flammata*), semilooper (*Autographa nigrisigna*), bean aphid (*Aphis craccivora*), termites (*Odonototermes obesus* and *Microtermes obesi*), pod-borer (*Etiella zinckenella*) and whitefly (*Bemisia tabaci*) are important ones (Lal and Rohilla, 2007).

### Pigeonpea

**Hairy caterpillars:** The larvae of these hairy caterpillars (*Amsacta albistriga*, *Amsacta moorei* and *Diacrisia* spp.) feed on the tender leaves, often resulting in complete defoliation of plants. Manual picking of egg masses and caterpillars and destroying them or application of quinalphos 3 kg a.i./ha or malathion 5% or endosulfan 4% @ 25 kg/ha can control this pest effectively.

**Pod-borer (*Helicoverpa armigera*):** The larvae feed on almost all plant parts, and at pod formation bore into pods and eat away all grains. This is one of the most severe pests in southern India. Application of solution of 0.06 % dithiocarb 75 WP or 0.2 % profenophos 50 EC or 0.02% methomyl 40 SP immediately after appearance of eggs, a second application of 5% NSKE (neem seed kernel extract), a third spray of NPV (nuclear polyhedron virus) @ 250 LE (larval equivalent)/ha will effectively control this insect. In case of incomplete control, a fourth spray with the solution of insecticides like 0.25% chlorpyrifos 20 CP or 0.2% quinalphos 35 EC or 0.02% endosulfan 35 EC to control these pests. If the problem persists, a fifth round of spray with 0.05 EC alfamethrin 10 EC or 0.1% fenvelerate 20 EC may be needed. Dusting the crop with quinalphos 3 kg a.i./ha or malathion 5% or endosulfan 4% @ 25 kg/ha will also be helpful in controlling this insect.

Recently, the integrated pest management concept is gaining popularity for the control of this pod borer. Joshi and Srivastava (2006) reported that the combination of deep summer ploughing, ridge sowing, installation of pheromone trap @ 20/ha, bird perches @ 20/ha, application of methomyl 40 SP @ 1 kg/ha, 5% neem-seed-kernel extract (NSKE) and *Bacillus thuringiensis* subsp. Kurstaka (Bt) @ 1 kg/ha recorded the best control of pod-borer and higher yield in pigeonpea (Table 8.31).

**Pod-fly:** The adult flies (*Melanagromyza obtusa*) lay eggs on the pods, and on hatching small larvae bore into pods and eat on the developing grains. Afterwards pupates inside and the adult fly comes out after maturity by making a bigger hole on the pod wall. This is the most severe pest in northern India. Spraying of systemic insecticides like monocrotophos (0.04%) or oxydemeton methyl (0.05%) or dimethoate (0.03%) during early pod formation prevents and controls the incidence of this pest.

**Bristle beetles:** The adult beetles (*Mylabris* spp.) feed heavily on the flowers and bring about flower drop and loss of flowers. This reduction in flowers results in reduced pods/plant and ultimately yield. Manual picking and



**Table 8.31** Yield and economics of integrated pest management (IPM) module in pigeonpea

Module	Yield (kg/ha)		Benefit : Cost ratio	
	2001	2002	2001	2002
M <sub>1</sub>	518.9	348.9	1.46	1.55
M <sub>2</sub>	767.8	796.7	3.22	3.35
M <sub>3</sub>	683.3	697.8	3.23	2.25
M <sub>4</sub>	601.1	624.4	1.65	1.72
M <sub>5</sub>	324.4	346.7	-	-
CD (P = 0.05)	81.8	67.9		

Source: Joshi and Srivastava (2006)

M<sub>1</sub>: Deep summer ploughing; Ridge sowing; Pheromone trap @ 20/ha; Bird perches @ 20/ha; 5% Neem seed kernel extract (NSKE); *Helicoverpa armigera* NPV @ 500 LE/ha

M<sub>2</sub>: Deep summer ploughing; Ridge sowing; Pheromone trap @ 20/ha; Bird perches @ 20/ha; Methomyl 40 SP @ 1 kg/ha; 5% Neem-seed-kernel extract (NSKE); *Bacillus thurengensis* subsp. Kurstaka (Bt) @ 1kg/ha .

M<sub>3</sub>: Deep summer ploughing; Ridge sowing; Pheromone trap @ 20/ha; Bird perches @ 20/ha; Profenofos 50 EC @ 1 liter/ha; 5% Neem seed kernel extract (NSKE); *Helicoverpa armigera* NPV @ 500 LE/ha

M<sub>4</sub>: Deep summer ploughing; Ridge sowing; Pheromone trap @ 20/ha; Bird perches @ 20/ha; Profenofos 50 EC @ 1 l/ha; 5% Neem seed kernel extract (NSKE); *Helicoverpa armigera* NPV @ 500 LE/ha; Endosulfon 30 EC @ 2 litres/ha.

M<sub>5</sub>: Sowing on flat-bed by seed broadcast; Pheromone trap @ 20/ha; No other treatments.

killing, and dusting with malathion (5%) or carbaryl (10%) @ 25 kg/ha reduces the loss due to this insect.

**Leaf webber:** Leaf webber moth (*Maruca testulalis* Syn. *M. amborinalis*) lays eggs singly on flower, pod and growing tips. Young one hatches in 2-3 days and they start eating flower, pod and growing tips after completely webbing these parts. Insects undergo molting four times and enter into pupation within 15 days. Adults will come out within 4-6 days and life cycle will be continued. Spraying solution of 0.2% quinalphos 35 EC or 0.02% endosulfan 35 EC or dusting with endosulfan or quinalphos @ 25 kg/ha is recommended.

The plant-protection measures employed for these pests also take care of other minor pests causing lesser damage. Besides control measures, use of resistant/tolerant varieties also reduces the yield losses due to insect-pests.

### Greengram and Blackgram

**Stem fly:** The maggots of stem fly (*Ophiomyia phaseoli*) bore into young stems and damage the stem. Leaves turn yellow and plants start wilting. Carbofuran applied as granules in the row at planting or spraying of carbofuran 40 F @ 2 kg/ha gives good control.

**Jassids:** Nymphs and adults of jassids (*Empoasca* spp.) generally feed on the lower side of the leaf, sucking out the juice and injecting toxic saliva into the cells. In severe infestation, the leaves curl at edges and turn brown, giving



the field a scorched appearance called hopperburn; most common in *kharif* season. Applications of 0.03% dimethoate or 0.04% monocrotophos 45 and 60 days after sowing are effective in protecting *kharif* greengram against lepidopteran pod borers and other pests attacking the crop at the flowering and fruiting stages (Ahmad *et al.*, 1998).

**Aphids (*Aphis craccivora*):** Both nymphs and adults suck the plant sap from leaf, stem and other vegetative parts. Pods too get affected.

**White flies:** The nymphs and adults of white fly (*Bemisia tabaci*) suck the plant sap from leaves and other tender parts. This acts as a vector for yellow mosaic virus. Application of 0.2 g thiamethoxam/litre at 15 DAS is effective against this pest (Ganapathy and Karuppiah, 2004). Application of imidacloprid (12.5 kg/ha), at 15 and 30 days after sowing effectively controls the white flies (Ghosh, 2008).

**Thrips (*Caliothrips indicus*):** They puncture the plant cells and feed on the cell contents. The affected tissue becomes discoloured and turns to brown and wither away. The affected flowers are often deformed and shed away prematurely.

The jassids, aphids, white flies and thrips are controlled by spraying of systemic insecticides like monocrotophos (0.04%) or dimethoate (0.03%) or demetonmethyl (0.05%) or malathion (0.06%) or endosulfan (0.07%) etc. Recently application of imidacloprid has been found effective against the thrips (Sreekanth *et al.*, 2004). The frequency and number of sprays depend on the severity and periodicity of infestation.

**Hairy caterpillar (*Diacrisia* spp.):** Younger larvae of this insect feed heavily on surface of leaves. While the older larvae feed on leaves, which results in severe defoliation. The control measures include hand picking of caterpillar and killing them; and spraying of systemic insecticides like endosulfan (0.07%) or dimethoate (0.03%) or quinolphos (0.05%).

**Pod-borers:** The larvae of these pod-borers (*Maruca testulalis*; syn. *M.amboinalis*, *Helicoverpa armigera* and *Etiella* spp.) feed on leaves and flowers, and on pod formation, bore into pods and feed on developing grains. The affected flowers and pods often drop away or result in pod deformation. Severe infestation causes reduction in grain yield. Spraying of endosulfan (0.03%) or malathion (0.05%) at the fruiting stage is quite effective in controlling the pod borers. Dusting of fenval [fenvalerate] 0.04% D, malathion 5% D, endosulfan 4% D, methyl parathion [parathion-methyl] 2% D and chlorpyrifos 1.5% D are efficient in curtailing the infestation of *Maruca testulalis* (Basavaraju *et al.*, 2002).

Deep ploughing to expose the soil-borne pests to hot sun, flooding with irrigation and removal of alternate hosts and timing of sowing in such a way that insect build up is minimum during the vulnerable stages help prevent the infestation and losses due to insect-pests.

**Nematodes:** In India, nematodes, viz. *Meloidogyne javanica*, *Heterodera vigni*, *Rotylenchulus reniformis*, *Tylenchorhynchus brassicae* and *Tylenchulus* spp., have been reported to parasitise on greengram.

Nematodes enter the plant through the root tips. Young plants may be killed and older plants become sickly in appearance. The above-ground symptoms of



nematode infestation are severe stunting, wilting, yellowing, crinkling and death of leaves and malformation of pods and seeds. Below the ground the root vascular system is blocked or disrupted, interfering with water and nutrient uptake and transport (Poehlman, 1991).

Nematodes may be controlled effectively through integrated management practices involving crop rotations, use of resistant varieties and use of nematicides, e.g. carbofuran, aldicarb etc., (Varshney and Dwivedi, 2002).

### Cowpea

Cowpea is known to be infested by many insect-pests. These cause heavy losses if proper plant-protection measures are not adopted. The important pests under Indian conditions are:

*Jassids (Empoasca kerri)*

*Thrips (Caliothrips indicus, Megalurothrips usitatus)*

*Aphids (Aphis craccivora)*

*White fly (Bemisia tabaci)*

The nymphs and adults of these insects suck the sap from plant parts. The affected plants turn pale yellow, shed leaves and growth becomes stunted. In severe cases, even flower and bud drop is also noticed. The white fly also acts as vector for yellow mosaic virus.

The protective measures include spraying of systemic insecticides like 0.03% monocrotophos or 0.03% dimethoate or 0.05% oxydemeton methyl or 0.05% malathion, at first appearance of the symptoms of these insects. Application of 0.03% phosphamidon or 0.025% methyl demeton or 0.03% dimethoate were found to control the aphids in cowpea (Choudhary *et al.*, 2003).

*Cutworms:* The caterpillars (*Agrotis ipsilon*) cut the emerging and tender seedlings during night time. Seed treatment with carbofuran may prove effective.

*Defoliators:* *Pagria costatipennis*, *Plusia nigrisigna* and *Spodoptera litura*

*Grasshoppers:* *Colemania sphenarioides*, *Chrotogonus* spp. and *Atractomorpha crenulata*

The defoliators and grasshoppers feed on leaves and other vegetative parts of the plants causing extensive damage to the total biomass and ultimately the yield. These may be controlled by collection and destroying of eggs and larvae of these insects in the early stages and by dusting with 10% methyl parathion or carbaryl @ 25-30 kg/ha.

*Pod-borers:* *Helicoverpa armigera*, *Maruca testulalis* (syn. *M. amboinalis*), *Cydia ptychora*, *Etiella zinckenella* and *Pachytychins mungonis*.

The larvae bore into the pods and feed on the developing grains. Deep cultivation may expose the pupae to sun and reduce the pest build up in the soil. Spraying of systemic insecticides like endosulfan (0.07%) or monocrotophos (0.04%) (Prajapati *et al.*, 2003) or quinalphos (0.05%) at flowering and pod-filling stage depending on the extent of pest incidence gives good control.

*Nematodes:* Many plant parasitic nematodes have been reported to infect and cause economic losses in cowpea. Important among these are: *Meloidogyne*



*javanica*, *Meloidogyne incognita*, *Heterodera trifolii*, *Rotylenchulus reniformis*, *Xiphinema lamberti*, *Pratylenchus* spp.,

All these species infect and damage the roots by making lesions, galls or root-knots. The plant growth is stunted, root system is under-developed and plants may die when the attack is severe in early stages. The detailed information on extent of damage and control measures under Indian conditions is not available. The application of neem-cake has been found to reduce the population and activity of root-knot nematode in cowpea (Goswami, 1993). Further seed treatment (ST) with *Paecilomyces lilacinus* at 5 g/kg was most effective in the reducing the total nematode population, especially the population of root-knot nematodes in cowpea (Pandey *et al.*, 2007).

### Horsegram

As the crop is grown in harsh conditions with minimum agronomic practices, not much work has been carried out on the pest and disease management in horsegram. Some of the major insect-pests observed in horsegram are: pod caterpillar (*Helicoverpa armigera*), pod fly (*Melanagromyza obtusa*), thrips (*Megalurothrips usitatus*), white fly (*Bemisia tabaci*), leaf minor (*Liriomyza trifolii*), leaf hopper (*Empoasca keri*), pod bug (*Clavigralla gibbosa*), pod-borer (*Maruca testulalis*), leaf minor (*Nacoleia vulgaris*) and hairy caterpillar (*Spilosoma obliqua*). The nature and extent of damage depends on several factors like weather conditions, crop stage etc. Further as horsegram is cultivated by the resource poor farmers, it may not be possible to go for costly inputs under low productivity conditions. It is therefore suggested to integrate cultural practices, use of resistant varieties and wherever possible chemical methods. Clean cultivation, manual killing of adults, spraying of insecticides like endosulfan (0.07%) or monocrotophos (0.04%) may be effective in controlling many of these insect pests.

### Mothbean

Mothbean is grown exclusively as rainy-season crop. The moist and humid condition coupled with sunny days is conducive for occurrence of many insect-pests and pathogens. Since the crop is grown in marginal and sub-marginal areas, the systematic studies on the occurrence of insect-pests and their control is not very comprehensive. The important insect-pests observed in the crop are jassids (*Empoasca terminalis*), white fly (*Bemisia tabaci*) and thrips (*Caliothrips indicus*) among sucking pests; hairy caterpillar (*Amarsaca moorei*) among chewing and biting; termites (*Microtermes obesi*) and white grub (*Holotrichia consanguinea*) among soil-borne insect-pests. Besides these, there are several other insect-pests whose damage is not that severe. The extent of damage is not available precisely. It is reported to vary from 10 to 50% under different agro-climatic conditions. As crop productivity itself is low, chemical control measures are seldom employed due to their high costs. Use of tolerant varieties, cropping techniques like appropriate time of sowing, crop rotation, use of some systemic insecticides like 0.04% monocrotophos, 0.03% dimethoate or 0.05% oxydemeton methyl or 0.05% malathion are sufficient to control many



of these insect-pests satisfactorily. Bairwa *et al.* (2006) reported that dimethoate 30 EC (0.03%) and methyl demeton [demephion] 25 EC (0.025%) proved to be most effective against whitefly in mothbean.

### DISEASES AND THEIR MANAGEMENT

The major diseases of *kharif* pulses have been listed in Table 8.32.

**Table 8.32** Important diseases of *kharif* season pulses

Crop	Disease	State
Pigeonpea	Sterility mosaic	Bihar, Gujarat, Karnataka, Tamil Nadu, and Uttar Pradesh
	Wilt	Andhra Pradesh, Bihar, Gujarat, Madhya Pradesh, Maharashtra
Greengram	Yellow mosaic	Bihar, Haryana, Uttar Pradesh, Punjab, Madhya Pradesh, Tamil Nadu, Karnataka
Blackgram	Powdery mildew	Maharashtra, Madhya Pradesh
	Leaf spot	Andhra Pradesh, Punjab, Haryana, Tamil Nadu, Uttar Pradesh
Cowpea	Mosaic	Prevailing in many growing areas
	Powdery mildew	
	Bacterial blight	
	Root rot	
Horsegram	Root rot	Tamil Nadu, Karnataka
	Powdery mildew	Karnataka
Mothbean	Root rot	Rajasthan

*Source:* Sharma and Jodha (1984); Prakash *et al.* (2002); Vanitha and Alice (2008); Naik (2001); Rathore and Rathore (1999)

#### Pigeonpea

The important diseases of pigeonpea are as follows.

**Wilt:** Wilt (*Fusarium oxysporum* sp. *udum*) is one of the most serious diseases in India affecting the pigeonpea. The affected plants show yellowing and drying of leaves followed by drying of entire plant. Roots and base of the stem show black streaks especially under the bark. Control measures include removal and destroying of affected plants, following mixed cropping and crop rotations and growing of resistant varieties like BDN 1, BDN 2, C 11, Maruthi etc. The seed dressing by *Pantoea dispersa* reduced wilt incidence (47%) and it was better than bavistin (41%) and *Trichoderma* Monitor WP (36%) treatments (Maisuria *et al.*, 2008).

**Sterility mosaic virus:** This is another serious disease known to occur in pigeonpea. Stunted growth, bushy and pale green leaves, mild mottle or ring spots on leaves and lack of reproductive parts are typical symptoms of this disease. A mite, *Aceria cajani*, transmits this disease. Spraying of metasystox (0.1%) controls this mite and disease spread. Removing and destroying the affected plants along with alternate hosts and growing of resistant varieties decrease the incidence of disease. The varieties, viz. ICP 7035 and ICP 8862, are resistant to this disease (Om *et al.*, 2008).



**Phytophthora blight:** The symptoms of phytophthora blight (*Phytophthora drechsleri* var. *cajani*) are sudden wilting of plant parts above the infected portion, upward rolling of leaves, withering of petioles, lesions on stems, petioles and leaves those are dark-brown to purple, often extending to 15-20 cm. The disease is often severe in early crop stage during the wet rainy months. Rouging and destroying affected plants, avoiding waterlogging and excess irrigation and growing resistant cultivars are some of the possible ways of reducing the incidence. Ridge sowing and intercropping with greengram reduced the intensity of this disease (Chauhan *et al.*, 2005).

**Leaf spot:** Grey coloured angular lesions with reddish brown margins on leaves are typical symptoms of leaf spot (*Cercospora canescens*). Application of zineb or captan (0.2%) at 10-12 days interval controls this disease.

### Greengram

**Yellow mosaic virus:** It is one of the most severe diseases in greengram. The affected leaves show scattered yellow specks. The yellowing spreads after some time and often the entire foliage becomes yellow. The infected plants show late maturity, fewer flowers and pods. The pods become crippled and bear fewer seeds. As this spreads through white flies, their control by spraying systemic insecticides like endosulfan (0.07%) or malathion (0.05%) reduce the spread of this disease. Further, growing resistant varieties is another option.

**Leaf spot:** The symptoms of leaf spot (*Cercospora canescens*) are lesions on leaves, which turn brown with reddish-brown margins. Similar spots are also seen on pods. Foliar spray of fungicides like captan or zineb @ 2 g/litres water or bavistin @ 0.5 kg in 1,000 litre water/ha controls the disease. Application of hexaconazole (Contaf 5% EC) at 0.005% or penconazole (Topas 10% EC) at 0.01% resulted in the highest seed yield and the lowest disease intensity (Khunti *et al.*, 2002).

**Dry-root rot:** Yellowing of leaves and wilting of plants are the symptoms of dry-root rot (*Rhizoctonia solani*). The stem of affected plant shows dark sunken lesions on the bark. The roots show dry-rot symptoms. Clean cultivation and crop rotation are important preventive measures reducing the inoculum build up in soil. Seed treatment with captan or thiram too reduces the incidence of this disease. Integration of *Trichoderma harzianum* as soil application (5 g/kg) + seed treatment with sub-lethal doses of carbendazim (0.02%) significantly reduced dry root rot incidence (Rajeswari *et al.*, 1999).

**Anthracnose:** The typical symptoms of anthracnose (*Colletotrichum lindemuthianum*) are brown sunken lesions on the cotyledons and young stems. Pods and seeds may also show such lesions. The affected seeds loose viability and fail to germinate. The disease is controlled by seed treatment with captan or thiram @ 2-3 g/kg seed or field spray of 0.2 % zineb at 10 days interval. Singh and Singh (2001) reported that 0.05% bavistin [carbendazim] or 0.10% benlate [benomyl] or 0.15% topsin M [thiophanate-methyl] treatment was effective in controlling this disease.

**Bacterial leaf spot:** The symptoms of bacterial leaf spot (*Xanthomonas axonopodis* pv. *phaseoli*) are brown dry elevated necrotic pustules that enlarge



and coalesce to form necrotic blotches. These disintegrate to give the leaf a ragged appearance. Streaks or cankers develop on the stem in severe infections. Use of resistant varieties like Jalgaon 781, ML 9, ML 10 etc. and seed treatment with captan reduce the incidence of this disease. Immersion of seeds for 25 minutes in concentration of 250 ppm solution of streptomycin and bactosan was effective in controlling the seed-borne bacteria (Dhutraaj *et al.*, 2001).

**Powdery mildew (*Erysiphe batatae*):** This is more common in post-rainy season crop. First small to medium-sized white powdery spots appear on leaves and afterward spread to stem too. Sulphur dusting @ 25 kg/ha or spraying of fungicides like carbendazim or benomyl gives good control against this disease. Application of hexaconazole (Contaf 5% EC) at 0.005% or penconazole (Topas 10% EC) at 0.01% too recorded very good control of powdery mildew (Khunti *et al.*, 2002).

**Mosaic mottle virus:** The affected plants show broad patches of light and dark green leaf areas, giving the leaf a mosaic pattern, blistering of the leaf blade, stunting and flower shedding. Use of healthy seeds free from seed-borne inoculum, growing of resistant varieties, and measures to control vectors such as aphids, white flies etc. reduce the incidence of this disease.

### **Blackgram**

**Leaf crinkle (*Blackgram leaf crinkle virus*):** Affected plants show crinkling leaves on upper surface and the stipules become thick and broader; buds and flowers give bushy appearance. It is spread through white flies. Application of 0.2 g thiamethoxam/litre of water at 15 DAS controls the vector and spread of disease.

**Mosaic mottle (*Blackgram mosaic virus*):** The symptoms appear as irregular light green patches on leaves alternating with green areas. Later, the leaves become distorted and margin curl upwards. The combination of seed soaking in 0.1% imidacloprid for 2 hours and dry seed treatment with carbendazim 50 WP + thiram 75 WP (1:1) at 2 g/kg seed followed by foliar sprays of 0.02% imidacloprid and 0.05% carbendazim 30 and 45 days after sowing, respectively, was the best treatment to control cercospora leaf spots (4.3%) and yellow mosaic (MYMV) (9.5%), consequently resulting in the highest grain yield (Dubey and Singh, 2006).

**Sterility mosaic (*Blackgram sterility mosaic virus*):** No flower formation is the symptom of this disease. The problem is minimized by use of resistant varieties, removal of affected plants and control of vectors like sucking insects by spraying systemic insecticides.

### **Cowpea**

**Bacterial blight:** It is a seed-borne disease and is caused by *Xanthomonas axonopodis* pv. *vignicola*. The germinating seedlings turn brown-red and die. Irregular to round spots brown in colour with chlorotic halos, appear on leaves, and later spread to stems. Stem may break. Pods are also infected leading to shriveled seeds. Use of healthy seeds and growing resistant varieties are easy and low-priced methods of preventing and controlling this disease.



**Seedling blight:** This is caused by soil-borne fungus, *Phytophthora vignae*. The young seedlings die due to tip burning. Necrotic lesions encircle stem near the base and plant wilts. Providing good drainage, clean cultivation, removing affected plants and growing resistant varieties are simple and easy methods of reducing the incidence of this disease. Seed treatment with thiram + carbendazim (1.25 + 1.0 g/kg seed); carbendazim or thiram or mancozeb 75% WP at 2 g/kg seed; metalaxyl at 1.0 g/kg seed and thiophanate-methyl at 1.5 g/kg seed were effective in controlling the fungi and improving seed germination (Kumar *et al.*, 2004).

**Wilt:** Wilt (*Fusarium oxysporum*) affected young plants start drooping with green leaves. The stem when cut shows brown discolouration. Seed treatment with thiram or captan @ 2.5 g/kg seed, rouging infected plants and growing resistant varieties reduce the damage.

**Rust:** Appearance of circular reddish brown pustules on leaves, stems and pods are the symptoms of rust (*Uromyces phaseoli* var. *vignae*) in cowpea. Dusting of sulphur @ 25 kg/ha or spraying wettable sulphur @ 2-4 kg/ha and growing of resistant varieties may be effective.

**Powdery mildew:** The plants affected by powdery mildew (*Erysiphea polygoni*) show white powdery spots on leaves and stems and in severe cases entire foliage turns yellowish. The control measures are similar to those for rust.

**Cowpea mosaic:** This is a viral disease transmitted through vectors. In severe infestation, 100% yield loss has been observed (Frison, 1988). While the yellow mosaic virus is transmitted through aphids, the golden mosaic virus spreads through white flies. Affected plants show chlorotic areas, later covering the entire leaves turning them yellow. Using resistant varieties, clean and healthy seed, rouging and destroying of affected plants are some of the preventive measures. Spraying of systemic insecticides like monocrotophos or methyl parathion controls the horizontal spread of disease through control of vectors.

### **Horsegram**

Among the diseases, anthracnose (*Colletotrichum lindemuthianum*), dry root rot (*Macrophomina phaseolina*), leaf spot (*Cercospora canescens*), rust (*Uromyces phaseoli* var. *vignae*), powdery mildew (*Leveillula taurica*), aerial blight (*Rhizoctonia* spp.), yellow mosaic etc are important. The intensity of disease, loss in productivity of crop depends on several factors like prevailing agro-climatic conditions, agronomic practices followed etc. Here again the cultural methods like clean cultivation, use of resistant varieties, seed treatment with *Trichoderma viride* @ 4g/kg seed, fungicides like carbendazim (Vanitha and Alice, 2008) or thiram or mancozeb 75% WP at 2 g/kg seed, spray of systemic insecticides like monocrotophos (0.04%) to control vectors, carbendazim (0.1%), wettable sulphur (0.3%) and dinocap (0.2%) applied as foliar spray (Naik, 2000) will give satisfactory control of many of these diseases.

### **Mothbean**

Mothbean is also prone to many fungal, bacterial and viral diseases. Dry-root rot (*Macrophomina phaseolina*), blight (*Rhizoctonia bataticola*), pot rod



(*Choanephora cucurbitarum*) and leaf spot (*Myrothecium roridum*) among fungal diseases; bacterial leaf blight (*Xanthomonas* spp.) among bacterial diseases; and yellow mosaic virus (YMV) among viral diseases are prominent in mothbean. The occurrence and extent of damage also varies from season to season and location to location. The common control measures followed for these diseases in other crops are also effective in this crop. Seed dressings with bavistin 50 WP (carbendazim) (2 g/kg), topsin M-70 (thiophanate-methyl) (2 g/kg) and captan 75 SP (3 g/kg) were the most effective and economical in controlling dry root rot in mothbean (Rathore and Rathore, 1999). The seed treatment with *Pseudomonas fluorescens* was observed to reduce the root-rot disease by 69% (Singh, 2007).

### HARVEST AND POST-HARVEST CARE

#### Pigeonpea

Pigeonpea in general exhibits indeterminate growth and non-synchronous maturity. Prevalence of cold weather and moist soil conditions prolong the vegetative growth even after the pod bearing has started. It makes judgement regarding the time of harvesting quite tough. Varietal differences in harvesting time depending upon the days after podding and moisture content have been studied (Nimje and Gandhi, 1995). It is, however, considered ready for harvest, when about 75-80% of the pods start drying and change colour from green to brown or brownish-yellow. The plants are cut close to the ground level and shifted to drying yard. After sufficient drying, threshing is done either passing the stone roller, tractor or by beating with the heavy wooden sticks or using power-operated mechanical threshers. After separating the pigeonpea sticks, the threshed material is winnowed to get the clean seeds. Once the seeds have been separated from the chaff and other admixtures, the important operations include drying, grading, processing and storing. The seeds should be dried till the moisture content comes to around 10-12%. The high moisture content in the seeds reduces the keeping quality and makes the seeds vulnerable to insect and mould attack. As the harvesting is done when some of the pods are still green, there will be some shrivelled and broken grains during threshing operation. It is therefore necessary to remove such material to improve the seed quality. Since seeds are consumed in the form of split cotyledons, i.e. 'dal' it is better to go for processing before storing. Power-operated hullers or processors do the splitting of seeds into dal. The dehulling operation is usually performed in 2 steps; the first involves loosening the husk from the cotyledons, and the second involves removing of husk from the cotyledons and splitting them using a roller machine or stone *chakki*. After processing one more cleaning and separation of broken cotyledons is necessary to improve the quality and market value of the produce. Care should be taken to treat the dried seeds to be stored for long time to use as seed material for the next season with suitable chemicals. Dusting with 10% malathion reduces the infestation of storage pests like bruchids. Keeping seeds in polythene bags and solarization by keeping them in sunlight recorded reduced bruchid population (Ghaffar and Chauhan, 1999). However, the seed germination was not affected by the solarization. The processed material may



be stored in gunny bags in the well-ventilated, damp-proof godowns free from insects, rats, bandicoots and other pests. Bags should be stored on a wooden platform to protect them from soil moisture.

#### **Greengram/blackgram/cowpea**

The time and method of harvesting depends on the nature of maturity. In varieties exhibiting synchronous maturity, harvesting is done by uprooting or cutting entire plant at ground level when the plants show about 90% maturity. The harvested produce is sun-dried in threshing yard and after the moisture level has come down, it is threshed by trampling either by animals or tractor; or by beating with wooden sticks. The grains are separated from plant parts and other admixtures by winnowing. If the variety is of non-synchronous maturity, pods are harvested manually as and when they mature. This is a long and labour intensive process, accounting for 25-30% of the total production cost and 40-50% of the labour cost. The number of pickings and duration of harvest time depends on the variety. The pod picking should be done preferably during morning or evening hours to prevent shattering losses while handling the pods. The harvested pods are sun-dried and threshed by animal trampling or beating with wooden sticks. The grains are separated from the husk and cleaned by winnowing. The seeds are graded according to size by passing through appropriate sieve and separated from broken grains. The moisture content of the seed should not exceed 12% before being stored in godowns. The storage place should be dry and properly ventilated; and free from insect-pests, pathogens and rodents. Dusting with 10% malathion dust may effectively control the infestation with stored insect-pests. Coating seeds with edible oil @ 5-10 ml/kg seed may also prevent hatching of bruchid eggs and their infestation without adversely affecting bio-chemical properties of seeds. Dhulia *et al.* (1999) reported that greengram seeds could be protected from damage by the pulse beetle, *Callosobruchus maculatus*, for a long period by vegetable mustard, groundnut, rapeseed, sesame and castor oil treatment at 0.5% (w/v). This treatment did not have any adverse effect on the cooking quality of treated seeds.

In cowpea, the harvest of pods for vegetable purpose may start with the grain filling in tender pods. The harvest can continue for some time before increased fibre content and insect pest attack like aphid affecting the quality of pods. The spray of chemicals to control the insects often makes the harvest of pods unfit for consumption. The duration of harvest for pods depends on the quality of the pods and the variety. Irrigation at podding stage often enhances the availability of pods for vegetable purpose.

#### **Horsegram/mothbean**

Both horsegram and mothbean are grown in moisture-constraint situations. The crops are often forced to mature early. Due to declining soil moisture and high temperatures, the crops mature and dry up quickly. The crops are harvested by cutting the entire plants at ground level. The harvesting should be done preferably in the morning or evening hours to avoid the shattering losses. The



harvested material should be heaped at threshing yard and threshed either by animal trampling or by beating with the wooden sticks. The seeds are separated from the husk by winnowing. After drying the seed to maintain 10% moisture, these should be stored in well-ventilated place free from insect-pests, rodents etc. The place should be dry and cool to store the material for longer time. Seeds stored in 700 gauge poly bags recorded no bruchid infestation up to 18 months compared with those stored in cloth bags (bruchid infestation started after 9 months). Among the different pesticidal seed treatments, deltamethrin (0.04 ml/kg) + thiram (2.5 g/kg) gave complete protection (up to 18 months) under ambient condition (Jolli *et al.*, 2005).

The seeds contain high tannin and phytate in them impairing their nutritive value. They can be reduced by soaking the seed and germinating the seeds before using them (Rodge *et al.*, 2006). Autoclaving the seeds drastically suppressed the level of trypsin inhibitor, free polyphenols and haemagglutinins, which are considered to be antinutritional factors in horsegram. Roasting too decreased markedly the level of trypsin inhibitor and haemagglutinin (Preeti *et al.*, 2000).

### CROPPING SYSTEMS

All the *kharif* pulses form an important component in cropping systems. Whether it is intercropping system or sequential cropping system, they are very useful components imparting stability and sustainability by their complimentary and additive effect to the system. The multiple cropping systems devoid of pulses in *kharif* season are likely to deplete plant nutrients, ground water and become unsustainable in a long run. Some of the important intercropping systems found popular with farmers in different regions along with suitable varieties of pulses are given in Table 8.33.

**Table 8.33** Popular intercropping systems with pulse crops

Intercropping	State adopting intercropping (variety of pulses)
<i>Pigeonpea (PP) as intercrop</i>	
Pearlmillet + PP	U.P. (T 7, Bahar) M.P. (T 7, Gwalior 3, C 11, NP (WR) 15)
Sorghum + PP	U.P. (T 7, Bahar, T 17) M.P. (T 7, Gwalior 3, T 17, NP (WR) 15, C 11) Maharashtra (C 11, BDN 2, No. 148, NP (WR) 15)
Maize + PP	Bihar (Bahar, Sharad, Basant, BR 65) U.P. (T 7, Bahar)
Groundnut + PP (Paired row)	Gujarat (Tur 15-15, NP (WR) 15, BDN 2) A.P. (C 11, Hy 3C, LRG 36, BDN 1)
Cotton + PP (Paired row)	M.P. (T 7, Gwalior 3, NP (WR) 15, C 11) Maharashtra (C 11, BDN 1, BDN 2, No. 148, NP (WR) 15) A.P. (C 11, Hy 3C, LRG 36, BDN 1) Karnataka (C 11, Hy 3C, BDN 2)
Castor + PP	Gujarat (Tur 15-15, NP (WR) 15, BDN 1) A.P. (C 11, Hy 3C, LRG 36, BDN 1, ST 1) Gujarat (Tur 15-15, NP (WR) 15, BDN 2)

Table 8.33 contd



Table 8.33 concluded

Intercropping	State adopting intercropping (variety of pulses)
Small millets + PP	U.P. (T 7, Bahar, T 17) M.P. (T 7, Gwalior 3, NP (WR) 15, C 11) Bihar (Bahar, Sharad, Basant, BR 65) Karnataka (C 11, Hy 3C, BDN 2) Bihar (Bahar, Basant, BR 65, Sharad)
Turmeric + PP	
Greengram (GG) as intercrop	
Pigeonpea + GG	U.P. (T 44, PDM 11, PDM 54, Pant Mung 2, ML 267, PS 16, Pusa 105) M.P. (T 44, PDM 11, PDM 54, ML 267, PS 16, Pusa 105) Rajasthan (T 44, K 851, PS 16, ML 337, S 8) M.P. (T 44, PDM 11, PDM 54, ML 267, PS 16, Pusa 105) Maharashtra (Jalgaon 781, PDM 11, PDM 54, ML 267, PS 16, Pusa 105) Karnataka (Pusa Basanti, ML 131, PS 16) U.P. (T 44, Pant Mung 2, PDM 11, PDM 54) W.B. (T 44, PDM 11, B 1)
Sorghum + GG	
Cotton + GG	
Sugarcane + GG	
Sunflower + GG	
Blackgram (BG) as intercrop	
Pearlmillet + BG	U.P. (T 9, Pant U 19, PDU 1, UG 218) M.P. (T 9, Pant U 19, Pant U 30, PDU 1, PS 1, K 3) Rajasthan (Krishna, Pant U 19, PDU 1) M.P. (T 9, Pant U 19, Pant U 30, K 3, PDU 1, PS 1) Maharashtra (T 9, TPH 1, No. 55, Pant U 30, PDH 1, Sindhkheda 1-1)
Sorghum + BG	
Cotton + BG	
Pigeonpea + BG	U.P. (T 9, Pant U 19, PDU 1, UG 18) M.P. (T 9, Pant U 19, Pant U 30, K 3, PS 1, PDU 1) Bihar (T 9, Naveen, BR 68, Pant U 19, PS 1, PDU 1) U.P. (T 9, Pant U 19, PDU 1) U.P. (T 9, Pant U 19, PDU 1)
Sugarcane + BG	
Sunflower + BG	
Cowpea (CP) as intercrop	
Pearlmillet + CP	Rajasthan (C 152, JG 5, RC 19)
Pigeonpea + CP	Karnataka (C152, S488, V 16, V 24)
Horsegram (HG) as intercrop	
Acacia ( <i>Acacia tortilis</i> ) + HG	Rajasthan (Maru Kulthi)
Ber ( <i>Ziziphus rotundifolia</i> ) + HG	Rajasthan (Maru Kulthi)
Mothbean (MB) as intercrop	
Pearlmillet + MB	Rajasthan (RMO 40, Jwala and IPCMO 912)

U.P., Uttar Pradesh; M.P., Madhya Pradesh; A.P., Andhra Pradesh; W.B., West Bengal  
Source: Lal and Mishra (1996); Sharma (2003); Yadav and Jat (2005).

### Pigeonpea

Pigeonpea can be knitted into many cropping systems, viz. intercropping, mixed cropping, sequential cropping etc. The initial slow growth, deep rooting pattern, ability to tolerate drought and low soil moisture, has made it highly suitable crop for intercropping systems. It is intercropped with many short-



duration legumes, cereals and commercial crops. The short-duration cultivars of low sensitivity to temperature and photoperiod have been developed as an alternative to traditional ones. The new types fall into extra short-duration (<110 days) and short-duration (110-130 days) categories. These are adapted to vast geographical regions and a wide range of cropping systems. Some of the important cropping systems are listed below.

*Intercropping systems involving pigeonpea:*

- a. With cereals, such as, sorghum, finger millet, maize, pearl millet and rice.
- b. With legumes, such as, greengram, blackgram, field bean and cowpea.
- c. With oilseeds, such as, soybean, groundnut, castor, sunflower and sesame.
- d. With other crops, such as, cotton and sugarcane.

The row proportion varies with the component crop and variety used. Most of the cereals are grown in 3:1, 6:1 or 6:2 ratios. While the short-duration legumes are grown between pigeonpea rows without additional row spacing. As these crops are harvested quite early, there is no adverse impact on the yield of the pigeonpea. The row proportions with other crops vary according to farmer's convenience and growth pattern of the varieties used. With the arrival of early varieties of pigeonpea it has been possible to grow it as an intercrop in sugarcane also.

*Sequential cropping involving pigeonpea:* The pigeonpea as kharif season crop is grown in sequence in many sequential cropping systems. The important ones are: Pigeonpea-wheat/mustard-greengram; Pigeonpea+greengram-wheat/mustard; Pigeonpea+blackgram-wheat/mustard; Pigeonpea+soybean-wheat/mustard; Pigeonpea+cowpea-wheat/mustard; Maize-pigeonpea; Pigeonpea-sugarcane; Pigeonpea-potato-blackgram/greengram

When pigeonpea is grown as rabi/summer crop, it is involved in the sequential cropping systems of : Rice-pigeonpea, Maize-pigeonpea, Sorghum-pigeonpea, Pearl millet -pigeonpea.

The suitability of the pigeonpea in these sequences depends on timely or late sowing, availability of irrigation or assured rainfall, and availability of short-duration varieties etc. With the complementary effect of pigeonpea on soil fertility improvement, nutrient recycling, smothering of weeds and efficient utilization of soil moisture under different cropping systems it occupies more area in cropping systems than as a sole crop.

### **Greengram**

Greengram is grown in all the three seasons, viz. rainy (*kharif*), winter (*rabi*) and summer. However, it is seldom grown in the same agro-climatic zone in all the three seasons. Thus it is grown in different regions in different seasons.

With the development of short-duration varieties having low/no photoperiod sensitivity, greengram finds place in many cropping systems. Three important multi-cropping systems where greengram is involved are relay cropping, intercropping and mixed cropping. In relay cropping the greengram is grown in rotation with other crops generally as secondary crop, both crops being grown within the same year.



The important crop rotations involving summer/spring greengram are: Rice-rice-greengram; Rice-wheat-greengram; Potato-wheat-greengram; Maize-wheat-greengram

In *kharif*, greengram is grown in the following sequential cropping systems;

Greengram-wheat/barley/mustard/maize

Greengram-potato

In *rabi*, it is grown in the following sequences:

Pigeonpea-greengram

Sorghum/maize-greengram

Rice-greengram

The relay cropping of greengram besides making better use of land during off-season where no crop can be grown, it provides family employment and uniform distribution of labour requirement throughout year, improves soil fertility status with atmospheric nitrogen fixation and adds to protein production where cereals are the major crops during the main season.

Greengram is also grown as an intercrop and mixed crop in many areas. Its growth pattern and short-duration makes it suitable intercrop in many cereals and other crops.

Pigeonpea + greengram

Sorghum + greengram

Maize + greengram

Pearlmillet + greengram

Growing of intercrop imparts stability to cropping systems and insures against failure of one or other crop owing to some unexpected reasons. The row proportions and planting geometry vary from area to area and depends on varieties and growers' needs. The mixed cropping systems involving greengram are practiced in areas where there is scarcity of moisture and risks of failure of crops for want of moisture is very high and agricultural development is still at lower ebb due to harsh climatic conditions and/or poor soil conditions.

### **Blackgram**

Blackgram is grown in intercropping as well as sequential cropping.

*Intercropping systems:* It is intercropped with cereals, pulses oilseeds and some cash crops, such as (a) cereals: sorghum, maize and pearl millet; (b) pulses: pigeonpea; (c) oilseeds: groundnut, sesame, sunflower, castor and soybean and (d) cash crops: cotton, sugarcane.

The row proportions and method of planting varies with area to area and farmers' requirement.

*Sequential cropping:* Blackgram is grown in many cropping sequences in summer and *kharif* seasons. It is grown in summer under irrigated conditions in intensive agriculture system without wasting the intervening period between two main season crops of *rabi* and *kharif*. In areas where there is limited irrigation facility it is grown in *kharif* either as sole or intercropped with other crops followed by *rabi* crops. The cropping sequences involving blackgram are: Rice-rice-blackgram; Rice-wheat-blackgram; Potato-wheat-blackgram; Pigeonpea-wheat-blackgram; Blackgram-barley; Blackgram-wheat; Maize-potato-



blackgram; Maize-*Toria*-blackgram; Cowpea-potato-blackgram; Maize-mustard-blackgram; and Maize-blackgram-wheat.

### Cowpea

It is grown as intercrop in most of the *kharif* crops, such as sorghum, maize, pearl millet, pigeonpea etc. It is also grown in many cropping sequences like Rice-wheat-cowpea; Pearl millet-wheat-cowpea; Pigeonpea-wheat-cowpea; Rice-rice-cowpea; Sorghum+pigeonpea-cowpea; Cowpea-wheat-green gram; Maize-potato-cowpea; Rice-mustard-cowpea; Maize-potato-wheat-cowpea (fodder); and Cowpea-cotton-wheat.

### Horsegram

Horsegram is a very versatile crop suitable for using in various cropping systems. It is grown in many intercropping as well as sequential cropping systems. It is intercropped with sorghum, niger, sesame, finger millet, maize, sunflower etc. It is also grown in sequential cropping systems, viz. Horsegram-finger millet; Rice-horsegram; Maize-horsegram; Sorghum-horsegram; Finger millet-horsegram; Horsegram-sesame; Foxtail millet-horsegram; Sorghum-finger millet-horsegram; Field bean-finger millet-horsegram.

As a *rabi* crop, blackgram is grown in rotation with rice, sorghum and tapioca etc. in southern and eastern plateau and their hill regions and also in east and west coast plains and their hill regions. Blackgram is a very popular *rabi* crop for rice fallows to utilize the residual moisture and fertility.

### Mothbean

Mothbean is grown in many intercropping systems. The important intercropping systems involving mothbean are: Pearl millet + mothbean; Sorghum + mothbean; Maize + mothbean; Sunflower + mothbean.

However, since it is mostly grown in arid regions, it is rarely grown under sequential cropping systems owing to moisture constraints.

### SUMMARY

- Pigeonpea, green gram, blackgram and cowpea are the most important pulse crops grown during *kharif* season all over India, while horsegram and mothbean are important crops in southern and western region of the country, respectively. The states having the largest area under individual crops are: Maharashtra for pigeonpea, Rajasthan for green gram and mothbean, Uttar Pradesh for blackgram and Karnataka for horsegram.
- All these crops being tropical and sub tropical in nature, occupy the largest area in India among all the countries growing them.
- The grains being rich in protein, carbohydrates, minerals, vitamins and crude fibre constitute major component of vegetarian diet of vast majority of the people of the country.
- *Kharif* pulses are grown on a variety of soils under varied agro-climatic conditions throughout the country. Inherently highly drought-tolerant crops, they are preferred even in areas receiving scanty rainfall.



- Pigeonpea is a long-duration woody shrub needing more than 120 days for maturity, while the remaining crops are short-duration ones needing as short as 60 days for maturity as in the case of greengram.
- Greengram, blackgram, cowpea, horsegram and mothbean are short-stature annual bushy plants.
- Pulses are basically short day plants needing longer nights and shorter days for flowering. However, with breeding of photo-insensitive and thermo-insensitive varieties, they can also be grown in other seasons, viz. winter and summer.
- Although pulses do not need very fine tilth, proper soil preparation is desired to free field from perennial weeds, cloddy structure and leveling helps achieve good germination and crop stand.
- It is necessary to have good drainage to flush out water after heavy showers and prevent water stagnation, which affects the crops adversely in areas of medium to high rainfall and water conservation in low rainfall areas.
- Selection of appropriate variety, clean and viable seeds, seed treatment with fungicides like thiram or captan @ 2-3 g/kg seed to prevent seed borne diseases is important.
- Inoculation with appropriate cultures of *Rhizobium* and phosphorus solubilizing bacteria (PSB) helps in raising good and vigorous crop.
- The seeding time depends on onset of monsoon, irrigation facility and crop variety. The *kharif* sowing is usually done just prior to or after the onset of monsoon. The winter crop is planted during September and summer crop from February to April. However, the exact time of sowing depends on agro-climatic conditions prevailing in a given area.
- Among the methods of sowing, sowing in rows with appropriate inter- and intra-row spacing depending on plant structure and its duration is recommended. However, in *para or utera* cropping systems broadcast of seeds to harness residual moisture before the harvest of main crop is practiced.
- A seed rate of 10-15 kg/ha for pigeonpea depending on variety and duration, 15-20 kg/ha for greengram and blackgram, about 25-30 kg/ha for cowpea, 25-30 kg/ha for horsegram and 10-15 kg/ha for mothbean is optimum.
- The plant population depends on spacing used and growth habit of variety. Usually short-duration and short stature varieties need higher plant population as compared to long-duration and profused branching types.
- Though these crops are capable of fixing atmospheric nitrogen in association with *Rhizobium*, application of nitrogen @ 20-25 kg/ha at sowing results in early vigorous establishment of plants. Further, application of 50-60 kg P<sub>2</sub>O<sub>5</sub>/ha is necessary for better growth and yield. Application of potassium depends on the soil-potassium status. Among the other nutrients, application of sulphur and zinc are found to positively influence the performance of these crops.
- Providing 1 or 2 irrigations during moisture stress period particularly at flowering and pod-filling stages increases the grain yield of these crops. However, waterlogging at any stage of crop growth is detrimental to crop performance.



- As these crops are raised in *kharif* season coinciding with onset of rainy season, weeds are a great menace. The first 6-8 weeks are critical for crop-weed competition. Unchecked weed competition reduces the grain yield of crops drastically. One or two hand weedings or inter-cultivations reduce the weed infestation to a great extent. Application of pendimethalin @ 0.50-0.75 kg/ha as pre-emergence spray is found to give effective control of most of the weeds.
- Many insect-pests and diseases are also noticed in these crops. Insect-pests like caterpillars, pod-borers, sucking pests like jassids, thrips etc., and diseases like wilt, yellow mosaic, leaf spot are common. The sucking pests are found to transmit many viral diseases. Selection of resistant/tolerant varieties and prophylactic sprays of systemic insecticides like monocrotophos (0.04%) or dimethoate (0.03%) etc. and seed treatment with fungicides reduce the incidence of insect-pests and diseases.
- By virtue of their wide adaptability and tolerance to adverse growing conditions, pulses are also knitted in many cropping systems, viz., mixed cropping, relay cropping, sequence cropping with cereals, oilseeds and other pulses. The choice of component crops depends on agro-climatic conditions, local requirements and farmers' needs. Thus each of these *kharif* pulses have different cropping systems in different areas.
- The harvesting of these crops is usually done by cutting the plants at ground level, when >80% of pods are matured and started drying. The harvested plants are dried and threshed to separate grains from pods and winnowed to separate seeds from husk and other plant parts. The harvesting time depends on the duration of the crop and weather conditions. Moist conditions prolong the harvesting time while dry and hot conditions hasten the harvesting process. The cleaned seeds after threshing are dried to maintain moisture of 10-12% before being stored in godowns.

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## **Rabi (Winter) Pulses**

**(Chickpea, lentil, fieldpea, lathyrus and frenchbean)**

*Masood Ali, J.P. Mishra, P.K.Ghosh and Naimuddin*

The winter (*rabi*) grain legumes, viz. chickpea (*Cicer arietinum* L.), dry pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.) and lathyrus (*Lathyrus sativus* L.), together contribute about 42% to the world pulse production from an area of about 24 million ha. Globally, chickpea occupies the highest area followed by dry pea, lentil, fababean and lathyrus. These pulses are generally concentrated in temperate and sub-tropical climate. Chickpea, lentil and lathyrus are predominantly grown in developing countries and peas in the developed countries. In India, chickpea is the most important rabi pulse followed by lentil, fieldpea and lathyrus. These crops are distributed in 12° to 32° N latitude but concentrated in the states of Madhya Pradesh, Uttar Pradesh, Rajasthan, Jharkhand, Chhattisgarh, Maharashtra, Andhra Pradesh, Bihar, Haryana, Gujarat, Karnataka, West Bengal and Odisha.

### **CHICKPEA**

Chickpea is an important winter grain legume having extensive geographical distribution. The word *Cicer* is derived from the Greek 'Kiros' referring to a well-known Roman family *Cicero*. *Arietinum* is derived from the latin word 'aries' meaning ram which refers to the ram's head shape of the kabuli chickpea. Chickpea is known by different names in various countries such as gram, *chana*, Bengal gram, pois, hoos, Hommos, grao-de-beco and garbanzo.

Chickpea is mostly consumed in the form of processed whole seed (boiled, roasted, parched, fried, steamed, sprouted, etc.) or *dal* (decorticated split cotyledons boiled and mashed to make a soup) or as a *dal* flour (*besan*). It is used in preparing a variety of snacks, sweets and condiments. Fresh green seeds are also consumed as a green vegetable. Chickpea is a good source of protein (18-22%), carbohydrate (52-70%), fat (4-10%), minerals (calcium, phosphorus, iron) and vitamins. It is an excellent animal feed. Its straw also has good forage value.

#### **Acreage and production**

*World:* On a global basis, chickpea is the third most important pulse crop

after dry beans (*Phaseolus vulgaris* L.) and dry peas. It has a wide geographical distribution covering Indian sub-continent, the Mediterranean region, western and eastern Asia, northern and eastern Africa, southern Europe and Australia. Thirty-four countries are reported to grow chickpea, however only 19 countries have more than 20,000 ha area. During 2009, the global chickpea production was 10.46 million tonnes. India, Pakistan, Turkey, Australia, Myanmar and Ethiopia are major chickpea-producing countries, contributing about 88% to the global production (Table 9.1). In recent years, Australia and Myanmar have emerged as important chickpea-producing countries ranking fourth and fifth in the World.

**India:** In India, chickpea is the premier pulse crop occupying 8.17 million ha and contributing 7.47 million tonnes to the national pulse basket (Table 9.2). It is grown throughout the country excepting on high altitudes of northern and north-eastern regions and coastal peninsula. The major

**Table 9.1** Leading-chickpea producing countries in world (2009)

Country	Production ('000 tonnes)
India	7,060.0
Pakistan	740.5
Turkey	562.6
Australia	445.0
Myanmar	398.0
Ethiopia	312.1
Iran	208.9
Mexico	165.0
Canada	75.5
Syrian Arab Republic	57.4
Yemen	50.6
Malawi	52.4
United Republic of Tanzania	38.3
Morocco	38.0
Spain	20.5
Algeria	17.8
Sudan	11.2
Israel	8.7
Italy	7.8
Tunisia	7.5
World Total	10,460.0

Source: FAO Yearbook, 2009

**Table 9.2** Area, production and productivity of chickpea in India (2009-10)

States	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
Andhra Pradesh	647	846	1,308
Bihar	57	58	1,014
Chhattisgarh	252	221	880
Gujarat	132	125	947
Haryana	84	62	738
Jharkhand	63	57	914
Karnataka	972	574	591
Madhya Pradesh	3,085	3,304	1,071
Maharashtra	1,291	1,114	863
Odisha	45	33	749
Rajasthan	884	534	604
Uttar Pradesh	618	509	824
West Bengal	22	24	1,110
Others	17	15	676
All India	8,169	7,476	915

Source: Agriculture Statistics, 2010



chickpea-producing states are Madhya Pradesh, Rajasthan, Andhra Pradesh, Maharashtra, Uttar Pradesh, Karnataka, Chhattisgarh, Gujarat, Haryana, Jharkhand and Bihar. During the last two decades, area under chickpea has progressively decreased in north India (Punjab, Haryana, Rajasthan, Uttar Pradesh, Bihar and West Bengal), whereas area has increased in central and southern regions (Andhra Pradesh, Maharashtra, Madhya Pradesh, Karnataka and Gujarat) owing to change in production base, cropping systems and comparative economics.

### Origin

Chickpea is an ancient crop whose earliest record dates back to 6250 BC. Most probably it originated from south-eastern Turkey and adjoining northern region of Syria wherefrom it spread to other countries with arid/semi-arid and sub-tropical environments. In addition to the cultivated *Cicer arietinum*, 42 wild species are known to exist. However, natural distribution of these wild species is restricted to countries around the Mediterranean Sea, Soviet Union, Ethiopia, Sudan and in the Himalayan Mountains of India.

### The plant

Chickpea is a diploid species with  $2n = 16$  chromosomes. It is a self-pollinated crop and belongs to sub-family Papilionaceae of the family Leguminaceae.

It is an annual plant with indeterminate growth habit. Stems are branched, flexuous or straight, erect to prostrate, and more or less ribbed. The number of primary branches may vary from one to eight, depending on the genotypes and growing conditions. They are thick, strong and woody and determine the general appearance of the plant. Secondary branches produced by buds located on primary branches are less vigorous than primary branches but contribute substantially towards seed yield. Tertiary branches growing from buds on secondary branches are rather leafy and bear fewer pods. The height of the plant may vary from 20 to 100 cm. Leaves are located alternate on the branch and consist of rachis and leaflets. Rachis length varies from 3 to 7 cm and each rachis supports 10 to 15 leaflets which are typically serrated. Stipules are 3-5 mm long, 2-4 mm wide and toothed. The entire surface of the plant shoot, except the flower is densely covered with fine hairs (trichomes). Many trichomes are glandular and secrete malic, oxalic and citric acids. These acids help in protecting the plants against insect-pests.

Chickpea roots are robust and strong. The plant has a deep tap-root system with a few laterals which help in drawing moisture from deeper soil layers and thus thrive under dryland conditions. The roots bear *Rhizobium* nodules which are crotalorioid type, branched and laterally flattened.

Flowers are typically papilionaceous. They emerge on axillary peduncle 6-13 mm long in the leaf axil. Generally, single flower is produced on each node; however, twin flowers have also been found in some cultivars. Petals are generally purple in *desi* type and white to beige to pale cream in *kabuli* types. Purple-flowered *desi* types generally contain high amount of anthocyanin pigment, and their leaves, stems and seed-coats are generally dark. *Kabuli* types,



which lack anthocyanins, have light green leaves and stems and pale seeds. Chickpea produces profuse flowers but only 20-30% flowers set pods. The pods are typically inflated ending in a mucro which sometimes looks like a thorn. The number of pods per plant may vary from 30 to 150, depending on genotypes and growing conditions. The pod size also shows great variation but it is least affected by environment. Seeds are characteristically 'beaked' sometimes angular with a ridged or smooth seed-coat. Seed colour varies from chalky white to burgundy and brown to black and is determined by colour and thickness of seed-coat and the colour of cotyledons. The number of seeds per pod varies from 1 to 3.

### Varieties

There are two types of chickpea, i.e. *desi* and *kabuli*. *Desi* types have small seeds with angular shape edge and pigmented seed-coat, which may vary from black-brown to cream or yellow. Its shape is similar to chicken's head with a characteristic 'beak', hence called chickpea. *Desi* types are grown predominantly in Indian sub-continent, East Africa and Australia. The *kabuli* types have large and round seeds with white, beige or pale cream seed-coat. *Kabuli* types are grown primarily in Mediterranean region, North Africa, Southern Europe and Central and South America. About 90% of the world's chickpea crop is the *desi* type.

In India, chickpea varietal development programme started with establishment of the Imperial (now Indian) Agricultural Research Institute, Pusa, Bihar in 1905. In early years, collection of local land races and their evaluation for adaptability and higher yields were the major activities. This led to release of 4 cultivars, viz. NP 17, NP 25, NP 28 and NP 58, in 1926. Systematic varietal improvement work was launched after inception of the All India Coordinated Pulses Improvement Project in 1967. Till date, over 200 varieties of chickpea have been released for cultivation. Some of the recently released varieties have resistance/tolerance to major diseases like *Fusarium* wilt (Avrodhi, KWR 108, JG 74, JG 315, Vishal, Vijay, Pusa 391, Bharti, ICC 32, Pusa 244) and *Ascochyta* blight (Pusa 261, Gaurav, GNG 146, GNG 469) besides being more productive. Early-maturing varieties (PBG 1, Udai, Pusa 372) amenable for late planting under rice production system have been developed. Emphasis has also been laid on developing bold-seeded genotypes both of *kabuli* (JGK 3, Phule G 0517, ICPK 2000-29) and *desi* types (K 850, Pusa 256, Vishwas, Vishal, Pusa 362, Dig Vijay). Varieties having tolerance to salt (Karnal Chana 1) and non-lodging under high input management (DCP 92-3) have also been released.

At present, 91 varieties are under seed production chain. Salient features of some of the ruling/recently released varieties are given in Table 9.3.

### FIELDPEA

Fieldpea (*Pisum sativum* L.) also called as pois proteagineux in French, guisante in Spanish, pisello in Italian, futtererbse in German and 'matar' in Hindi, is an important winter season grain legume crop largely confined to cooler temperate zones. There are two types of cultivated pea, i.e. garden pea and fieldpea. Garden peas are harvested in an immature condition and cooked as fresh or canned for subsequent uses. The fieldpea is generally grown for dry



Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
Haryana Chana 1	CCS HAU	1990	22-23	145-150	NWPZ	For late sowing, wilt resistant
Phule G 12	MPKV	1990	21	100	Maharashtra	
GPF 2	PAU	1990	21	157	NWPZ	Tolerant to <i>Ascochyta</i> blight
Uday (KPG 59)	CSAUAT	1992	18-20	138-140	NWPZ, NEPZ	For late sowing, tolerant to wilt, seed light brown
Bharti (ICCV 10)	ICRISAT	1992	18-20	95-100	South Zone	Resistant to wilt and dry root rot
Pusa 329	IARI	1993	21-22	145-155	NWPZ	Moderately resistant to wilt, bold seeds
Pusa 372	IARI	1993	14-15	110-140	NWPZ, NEPZ and Central zone	For late sowing, seed small, light brown
Sweta (ICCV 2) ( <i>kabuli</i> )	ICRISAT	1993	12-13	80-90	Maharashtra	Wilt resistant, seed bold, white
Vijay (Phule G 81-1-1)	MPKV	1994	18-20	105-110	Central zone	Wilt resistant, seed bold, wrinkled and yellowish brown
Pusa 362	IARI	1995	23-24	145-150	NWPZ	Bold-seeded, yellowish brown
GNG 663 (Vardan)	RAU, Sri-ganganagar	1995	22-25	150-155	NWPZ	Tolerant to wilt and <i>Ascochyta</i> blight, seed small yellowish brown
Sadbhawana (WCG 1)	RAU, Rajasthan	1996	20-22	145-150	NWPZ	Resistant to <i>Ascochyta</i> blight, tolerant to wilt and root rot
JG 218	JNKVV	1996	18-19	115-120	Madhya Pradesh	Tolerant to wilt
Alok (KGD 1158)	CSAUAT	1996	19-21	140-150	NWPZ	Resistant to wilt and root rot
Vishal	MPKV	1996	18-22	110-115	Central zone	Suitable for rainfed areas
KWR 108	CSAUAT	1996	20-23	130-135	NEPZ	Resistant to wilt, seed wrinkled, dark brown

Table 9.3 contd

Table 9.3 contd

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
Pant G 186	GBPUAT	1996	18-20	135-140	Uttar Pradesh	Suitable for late sowing, small-seeded
GNG 469 (Samrat)	RAU, Sriganaganagar	1997	20-22	145-150	NWPZ	Tolerant to Aschochyta blight and wilt, bold seeds
JGG 1	JNKVV	1997	13-15	120-125	Madhya Pradesh	Seed pink
Pusa 391	IARI	1997	17-18	110-120	Central zone	Bold seed, light brown
PBG 3 (GF 89-133)	PAU	1997	15-17	160-165	Punjab	Tolerant to pod-borer
DCP 92-3	IIPR	1997	19-20	145-150	NWPZ	Resistant to lodging and wilt
Karnal Chana 1	CSSRI, Karnal	1997	22-25	140-147	NWPZ	For salt affected areas
Gulabi Akola 1	PDKV	1997	12	115	Madhya Pradesh	
JAKI 9218	ICRISAT	1997	18	120	Maharashtra	Resistant to wilt and root rot, bold seeds
JGG 322	JNKVV	1997	17	105	Madhya Pradesh	Bold seed, resistant to wilt
BDG 72 (Dharwad Pragati)	IARI	1999	25-30	114-124	Central zone	Moderately resistant to wilt and root rot, bold seed
L 551 (kabuli)	PAU	1999	18-20	135-140	Punjab	Tolerant to wilt
Gujarat Gram 1	GAU	1999	17-22	105-110	Central zone	Resistant to wilt
Pusa Chamalkar	IARI	1999	17-19	140-150	NWPZ	White bold seed, tolerant to wilt
BG 1053 (kabuli)						
WCG 2 (Surya)	SVBPUAT	1999	20-25	135-150	Uttar Pradesh	Resistant to root rot, tolerant to stunt and dry root rot
Co 3	TNAU	1999	9-11	80-85	Tamil Nadu	Extra bold, resistant to wilt and collar rot
Co 4	TNAU	1999	9-11	80-85	Tamil Nadu	Extra bold, resistant to wilt and collar rot
JG 322	JNKVV	1999	18-20	110-115	Madhya Pradesh	Resistant to wilt
Gujarat Gram 2	GAU	1999	22-24	95-100	Gujarat	Tolerant to wilt and bold-seeded

Table 9.3 contd



Table 9.3 contd

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
JG 11	ICRISAT/ PDKV/JNKVV	1999	15	97	South Zone	Semi spreading, bold-seeded, resistant to wilt and root rot
Pusa 1003 (kabuli)	IARI	1999	18	135	NEPZ	White seeds
HC 3	CCS HAU	1999	20	155	Haryana	
JGG 1	JNKVV	1999	14	130	Madhya Pradesh	Medium size, pink colour seed, resistant to wilt
Pant G 10 (WCG 10)	GBPUAT, Modipuram	1999	19	135	Uttar Pradesh	
Surya (WCG 10)	GBPUAT, Modipuram	1999	19	135	Uttar Pradesh	Semi-spreading, small size yellowish brown colour seed
KAK 2 (kabuli)	JNKVV	2000	17-18	125-130	Central Zone	Bold seeds, resistant to <i>Fusarium</i> wilt
Gujarat Gram 4 (GCP105)	GAU	2000	18-20	135-140	NEPZ	Resistant to wilt
PDG 4	PAU	2000	18	155	Punjab	
Virat (Phule G 95418)	MPKV	2000	20	112	Maharashtra	Resistant to wilt
Jawahar Grain 16 (SAKI 95-16)	JNKVV	2001	18-20	110-120	Central Zone	
Vaibhav (RG 2918)	IGAU	2001	14-15	110-115	Chhattisgarh	Seeds wrinkled and bold
Jawahar Gram 130	JNKVV	2002	15-16	110-115	Madhya Pradesh	Resistant to wilt
GNG 1292 (kabuli)	RAU, Sri-ganganagar	2002	24	147	Rajasthan	Semi-erect, field resistance against wilt and dry root rot
H K 1 (HK 89-131)	CCS HAU	2002	20	155	Haryana	Bold-seeded
JGK 1 (kabuli)	JNKVV	2002	15-18	110-115	Central Zone	Moderately resistant to wilt
Phule G 95311 (kabuli)	MPKV	2002	16-18	90-100	South Zone	Seeds bold, tolerant to wilt

Table 9.3 contd

Table 9.3 contd

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adaptation	Characteristics
<b>PBG 5</b>	PAU	2002	19	105	Punjab	Small brown-seeded, vegetative. Ascochyta blight. For rainfed areas
Anubhav (RSG 888)	RAU, Durgapura	2003	20-22	130-135	NWPZ	
Akash (CSJD 884)	RAU, Durgapura	2003	16	130	Rajasthan	For rainfed area, resistant to dry root rot and wilt, double podded
Ashar (RSGK 6)	RAU, Durgapura	2003	18	136	Rajasthan	
Abha (RSG 973)	RAU, Durgapura	2004	16	125	Rajasthan	Tolerant to dry root rot
Anuradhar (WG 39/2)	PORS, WB	2004	24	126	West Bengal	Dark brown wrinkled seeds, tolerant to wilt
HC 5 (HC 96-98)	CCS HAU	2004	24	155	Haryana	Resistant to wilt and root diseases
JG 412	JNKVV	2004	19	95	Madhya Pradesh	
JG 62	JNKVV	2004	23	115	Madhya Pradesh	Wilt susceptible and double-podded
Pusa 1103	IARI	2004	22	130	Delhi	
Anvita (RSG 931)	RAU, Durgapura	2004	20	135	NWPZ	Double-podded, moderately resistant to dry rot and wilt
Abhar (RSG 807)	RAU, Durgapura	2005	18	140	Rajasthan	Resistance to dry rot, high input management
Dig Vijay	MPKV	2005	17	110	Maharashtra	Yellow-brown large seeds, wilt resistant
Pratap chana 1	ARS, Kota	2005	13	90	Rajasthan	Early maturing, grown on conserved moisture
Pusa 1088	IARI	2005	23	140	Delhi	Bold-seeded, resistant against soil-

Table 9.3 contd



Table 9.3 contd

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
Pusa 1105	IARI	2005	19	145	Delhi	borne diseases, BGM and stunt, tolerant to moisture stress
Adhar (RSG 963)	RAU, Durgapura	2005	20	128	NWPZ	Large-seeded, moderately resistant to wilt and dry root rot
HK 2 (HK 94-135)	CCS HAU	2005	22	130	NEPZ	Tolerant to wilt and root diseases
Arpita (RSG 895)	ARS, Durgapura	2006	15	135	Rajasthan	Resistant to wilt and dry root rot
Asha (RSG 945)	ARS, Durgapura	2006	20	135	Rajasthan	Resistant to wilt and dry root rot
JG 1	JNKVV	2006	15	130	Madhya Pradesh	Moderately resistant to wilt
JG 226	JNKVV	2006	21	115	Madhya Pradesh	Resistant to wilt, table purpose
JGK 2	JNKW	2006	18	100	Madhya Pradesh	Responsive to fertilizer, good cooking quality
JGK 3 ( <i>kabuli</i> )	JNKVV	2006	15	115	Madhya Pradesh	Tolerant to collar root and dry root rot
Pusa 1108	IARI	2006	29	150	Delhi	Large-seeded, <i>Kabuli</i>
Apama (RSG 991)	RAU, Durgapura	2007	16	135	Rajasthan	Moderately resistant to wilt and dry root rot
Arpan (RSG 896)	RAU, Durgapura	2007	14	135	Rajasthan	For late-sown condition, good level of resistance to wilt and dry root rot
Aruna (RSG 902)	RAU, Durgapura	2007	20	135	Rajasthan	Double-podded, resistant to wilt and dry root rot
						Semi erect, resistant to wilt and root

Table 9.3 contd

Table 9.3 contd

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
<i>Gauri</i> (GNG 1499-K)	Durgapura ARS, Sri-ganganagar	2007	18	143	Rajasthan	rot Semi-erect plant, bold-seeded
<i>Pusa 547</i>	IARI	2006	18	145	NWPZ	Mutant, bold and golden brown seeds
<i>Sangam</i> (GNG 1488)	ARS, Sri-ganganagar	2007	15	111	Rajasthan	Semi-erect brown colour seed with smooth testa
<i>Pusa Shubhra</i> (BGD 128) ( <i>kabuli</i> )	IARI, Dhanwad	2006	18	120	CZ	Semi-erect, medium large beige seeds
<i>Rajas</i> (Phule G 9425-9)	MPKV	2006	19	145	NWPZ	Semi-erect, yellowish brown and bold seeds
<i>Gangaur</i> (GNG 1581)	RAU, Sri-ganganagar	2007	24	151	NWPZ	Semi-erect tolerant to wilt, <i>Ascochyta</i> 'light stunt' - root rot
<i>Abhilasha</i> (RSG 974)	ARS, Durgapura	2008	15	130	Rajasthan	Late sown, good level of resistance to wilt and dry root rot
<i>Ankur</i> (CSJ 140)	ARS, Durgapura	2008	16	128	Rajasthan	Good level of resistant to dry root rot
<i>Anshul</i> (RSG 959)	ARS, Durgapura	2008	15	130	Rajasthan	For rainfed areas, resistant to wilt and dry root rot
<i>JG 14</i>	JNKVV	2008	19	110	Madhya Pradesh	Late sown, wilt resistant
<i>JG 6</i>	JNKVV	2008	21	113	Madhya Pradesh	Resistant to wilt and moderately resistant to dry root rot, tolerant to drought

Table 9.3 contd



Table 9.3 concluded

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
WCG 3 Vallabh Kallier Chana 1	SVBPUAT	2008	19	135	Uttar Pradesh	Tolerant to salt
WCG 10	SVBPUAT,	2008	21	147	Uttar Pradesh	Tolerant to wilt, erect, seed smooth, bold
Sadbhavana	SVBPUAT	2008	20	135	Uttar Pradesh	Resistant to dry root rot
ICPK 2002-29 (kabuli)	IIPR	2009	21	108	Central Zone	Moderately resistant to wilt, BGM-33g/110
PKV Kabuli 4	PDKV	2010	20	110	Madhya Pradesh	Large seed (55 g/100 seed)
ICPK 2004-29	IIPR	2010	20	110-115	Central Zone	Moderately resistant to wilt
Phule G 0517 (kabuli)	MPKV	2010	18	105-110	Maharashtra, Madhya Pradesh, Karnataka	Large seed (59 g/100 seed)
Pant Kasuli chana 1	GBPUAT	2010	25	140	Uttarakhand	Tolerant to wilt
Gujarat Junagadh Gram 3	JAU	2010	15	110-115	Gujarat	Resistant to wilt

NWPZ, North-West Plains Zone, (Punjab, Haryana, Rajasthan, western Uttar Pradesh (U.P.), Delhi); NEPZ, North-East Plains Zone (eastern U.P., Bihar, Jharkhand, West Bengal, Odisha, Assam); Central Zone (South-west U.P., Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh); South Zone (Andhra Pradesh, Karnataka, Tamil Nadu); Wilt, *Fusarium wilt*

seeds which are used for a variety of snack preparations and *dal*. The mature pea is highly nutritive being rich in protein (22.5%), carbohydrate (62.1%), fat (1.8%), minerals (calcium, iron) and vitamins (riboflavin, thiamin etc).

### Acreage and production

**World:** Fieldpea is the second most important crop at global level after dry bean (*Phaseolus vulgaris* L.). It is cultivated on 6.18 million ha area with a total production of 10.48 million tonnes (Table 9.4). The field peas are distributed in Asia, Africa, Europe, North America and Australia. The major field pea-producing countries are Canada, Russia, USA, India and China. These countries together contribute 78% to the global field pea production. Other major field pea-producing countries are France, Australia, Ethiopia, Ukraine, United Kingdom and Pakistan. India ranks fourth after Canada, Russia and USA.

**India:** In India, fieldpea occupies an area of 0.76 million ha with an annual production of 0.67 million tonnes. The average productivity is 866 kg/ha. The major field pea-growing states are Uttar Pradesh, Madhya Pradesh, Jharkhand, Assam, Maharashtra and Bihar. The area and production of pea in different states are given in Table 9.5.

**Table 9.4** Leading drypeas (fieldpea) producing countries in the world (2009)

Country	Production ('000 tonnes)
Canada	3,379.4
USA	777.32
India	754.459
Russia	1,348.89
China	960
Australia	356
France	546.846
Ethiopia	235.872
Ukraine	493.6
United Kingdom	141
Pakistan	60.4
Myanmar	62
Colombia	50.088
Peru	50.372
Argentina	47.677
Serbia	38.895
Tanzania	37.838
Burundi	37.316
Rwanda	33.8
Poland	24.9
Total world	10,480.0

Source: FAO Yearbook, 2009

### Origin

Archaeological surveys indicate the use of pea during prehistoric period

**Table 9.5** Area, production and productivity of fieldpea in India (2009-10)

States	Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
Assam	21	13	612
Bihar	22	22	1,009
Chhatisgarh	17	6	343
Jharkhand	43	34	808
Madhya Pradesh	289	147	508
Maharashtra	17	9	521
Uttar Pradesh	312	400	1,283
West Bengal	9	12	1,255
Others	28	28	1,000
All India	758	671	886



dating back to 3000 BC. The most probable centre of origin of pea is Mediterranean region of Europe and Western Asia (Vavilov, 1926) including Italy, Soviet Republic, north-west India, Pakistan, Afghanistan, Tazakistan and Uzbekistan.

### The plant

Fieldpea is a diploid species with  $2n = 14$ . This is often self-pollinated crop and belongs to subfamily Papilionaceae of the family Leguminaceae.

*Garden pea (Pisum sativum var. hortense)*: It is an annual herbaceous plant with well-developed tap-root and many slender lateral branches. Stem is angular or round, fistular, glabrous and non-pigmented. Branching is variable. Leaves are compound, having 1-3 pinnae of oval or oblong shape of 25-50 mm length with mucronate tips. Inflorescence axillary, long peduncled, raceme with 1-2 flowers having small bracts and bractioles. Coloured flowers, 5 lobed campanulate calyx with papilionaceous standard carrolla large, orbicular and clawed, the wings clawed with a prominent spur. The keel is united and broader than the wings. Ten stamens, diadelphous with uniform oblong anthers. Ovary is flattened with a sharply bent style and hairy on the concave face.

Pods are of variable length and breadth, curved or straight. The colour varies from yellowish green to dark green with either acute blunt apices. In most of the cases lined by a thin parchment like sclerenchymatous membrane. Seeds are 4-10 in number, normally free, testa thin either colourless or green, hilum distinct and either colourless, brown or yellow, surface smooth, wrinkled, indented or dimpled.

*Fieldpea (Pisum sativum var. arvense)*: It is identical to garden pea in most of its characters except the leaf, flower colour, pod size, seed size and colour, etc. Leaves have sometimes greyish mottling. Peduncles are short and leaf axis pigmented. Flowers have purple or lavender colour standards, wings purplish red and keel greenish. Pods are small and sometimes purple in colour. Seeds are smaller than garden pea, angular and grey.

### Varieties

The first fieldpea variety, Type 163 was developed as early as in the year 1950. However, systematic varietal improvement work was started only with the inception of All India Coordinated Pulses Improvement Project in 1966. The varieties released during 1950-80 were medium to tall statured and most often susceptible to powdery mildew. During eighties, the importance of dwarf plant types for enhancing productivity was recognized and consequently systematic research programme to develop dwarf varieties was initiated. Efforts were also made to incorporate resistance to powdery mildew. The first powdery mildew-resistant variety Rachna (tall type), having high yield potential, was released in 1982. Subsequently, several varieties like Pant Matar 5, HUP 2, DMR 11 etc. have been developed. The first dwarf variety HFP 4 (Aparna) was released in 1988 which has a yield potential of more than 25 q/ha. Most of the leaves of this variety are converted into tendrils. The important varieties with their salient features are given in Table 9.6.

Table 9.6 Improved varieties of fieldpea released since 1990, and their salient features

Variety	Sources	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
JP 885	JNKVV	1992	21	135-140	Central Zone	Resistant to powdery mildew (PM)
Shikha (KFP 103)	CSAUAT	1993	20.4	130-140	NWPZ	Resistant to PM
Ankar (DMR 7)	IARI	1996	23.5	135	NWPZ	Resistant to PM
Uttara (HFP 8909)	CCS HAU	1997	22.5	135	NWPZ	Dwarf, resistant to PM
Sapna (KPMR 144-1)	CSAUAT	1997	18	125	Uttar Pradesh	Dwarf, resistant to PM
Jayantii (HFP 8712)	CCSHAU	1998	22.2	120-140	Haryana	Large seed resistant to PM
Maiyiya malar (HUDP 15)	BHU	1999	23.5	120-130	NEPZ and NHZ	Resistant to PM and tolerant to rust
Swati (KFPD 24)	CSAUAT	1999	22	110-125	Uttar Pradesh	Escapes leaf miner
Pusa Prabhat	IARI	2000	15.5	95-115	NEPZ	Extra early and resistant to PM
Ambika	IGKV	2000	15-20	100-125	Central Zone	Resistant to PM
Pusa Pana (DDR 27)	IARI	2001	17.6	110-115	NWPZ	Very early and dwarf
KPMR 400 (Indra)	CSAUAT	2001	20	105-115	Central Zone	Dwarf resistant to PM
KPMR 522 (Jay)	CSAUAT	2001	22.9	120-140	NWPZ	Dwarf resistant to PM
Shubhra (IM 9101)	IGKV	2001	15-20	90-95	Chhattisgarh	Resistant to PM
IPF 99-25 (Adarsh)	IIPR	2002	23	110-115	Central Zone	Resistant to PM
Pant Pea 14	GBPUAT	2004	20	120-125	Uttarakhand	Tolerant to rust and resistant to PM
VL 45	VPKAS	2004	15	150-160	NHZ	Resistant to wilt and rust
IPFD 99-13 (Vikash)	IIPR	2005	23	100-110	Central Zone	Resistant to PM
Pant Pea 13	GBPUAT	2005	20	125-145	Uttarakhand	Resistant to PM
IPFD 10 (Prakesh)	IIPR	2006	22	110	Central Zone	Resistant to rust and PM
Pant Pea 25	GBPUAT	2006	20	120-125	Uttarakhand	Resistant to rust and PM
Pant Pea 42	GBPUAT	2007	22	125-130	Uttarakhand	Resistant to PM
HPP 9426	CCSHAU	2008	25	135	NWPZ	Resistant to PM and rust
Pant P 74	GBPUAT	2009	22	120-130	Haryana, NWZ	Shining green, tolerant to root rot
IPF 5-19	IIPR	2009	22	120-130	NWPZ	Dwarf
TRCP 8	ICAR	2009	14	125-135	NEHZ	Res. to PM and moderately tolerant to rust
	Res. Complex					Resistant to PM

NWPZ, North-western plains zone; NEPZ, North-eastern plains zone



## LENTIL

Lentil is one of the man's oldest food crops. Its cultivation dates back to beginning of agriculture itself. *Lens* is a latin word which refers to the shape of the seed of lentil. Lentil is known by different names in various countries such as 'lentille' (French), 'linse' (German), 'lenteja' (Spanish), 'a das' (Arabic), 'mercimek' (Turkish), 'hiramame' (Japanese) and 'masur' (Hindi).

Lentil is a valuable human food. Mostly it is consumed as a dry seed (whole decorticated, decorticated and split). It is also ground into flour to make variety of preparations. In Indian sub-continent, it is commonly consumed as *dal* (seeds boiled and mashed into soup). It is also used in preparation of several snacks and sweets. The straw and pod walls have high feed value.

Dehulled lentil seeds contain 24-26% protein, 1.3% fat, 2.2% ash, 3.2% fibre and 57% carbohydrate. It is a rich source of calcium (68 mg/100 g seed), phosphorus (300 mg/100 g seed) and iron (7 mg/100 g seed). It is also rich in vitamins C and riboflavin.

### Area and production

**World:** Globally, lentil shares only 5% of the total area under pulses. It occupies 3.78 million ha area with annual production of 3.91 million tonnes (Table 7). It is predominantly grown in Asia, which accounts for 65% of world production. In Asia India is the major lentil-producing country (0.95 million tonnes) followed by Iran and Turkey. Globally Canada is the leading lentil-producing country, contributing 38.6% to the total global production. The USA, Australia, Nepal, China, Ethiopia and Syria are other important lentil-producing countries.

In the last 2 decades, lentil area has significantly increased in Asia (especially Bangladesh, India, Iran, Turkey and Nepal).

**India:** In India, lentil is the second most important winter pulse crop. The area, production and productivity during 2009-10 was 1.48 million ha, 1.03 million tonnes and 697 kg/ha, respectively (Table 9.8). Being a cool-season crop, lentil production is mostly confined to northern and central India. Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Rajasthan, Jharkhand and Asom are the major lentil-producing

**Table 9.7** Leading lentil producing countries in the world (2009)

Country	Production ('000 tonnes)
Canada	1,510.2
India	950
USA	265.76
Turkey	302.181
Australia	143
Nepal	147.725
Ethiopia	123.777
Syria	102.461
Iran	83.985
Bangladesh	60.537
China	120
Pakistan	14.4
France	11.9
Spain	12.6
Morocco	10.441
Yemen	8.047
Mexico	6.495
Peru	3.638
New Zealand	3.263
Malawi	2.737
World Total	3,910

Source : FAO Yearbook, 2009

**Table 9.8** Area, production and productivity of lentil in India (2009-10)

States	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
Asom	21	11	595
Bihar	175	150	880
Chhattisgarh	16	5	306
Haryana	5	4	800
Jharkhand	23	13	559
Madhya Pradesh	541	284	525
Maharashtra	9	3	364
Rajasthan	27	24	826
Uttar Pradesh	592	476	803
West Bengal	52	47	911
Uttarakhand	19	12	632
Others	3	2	667
All India	1,479	1,031	697

states. Uttar Pradesh and Madhya Pradesh together contribute 70% towards total national production. The highest productivity (911 kg/ha) is reported from West Bengal.

### Origin

The distribution of genus *Lens* indicates that the Mediterranean region was the probable area of its domestication; however, there are significant differences in the distribution of individual species such as *culinaris*, *orientalis* and *nigricans*. The area from western Turkey to southern Iraq contains all wild species of lentil as well as *Vicia lentata*, a dubious species that can be defined as a lentoid 'Vicia'. This region seems to be the cradle of 'lentoid' characters viz. flattened pods and seeds.

Lentil is of ancient cultivation in Egypt, Southern Europe and Western Asia. From these areas, it spread northward to Europe, eastward to India and through much of China, and southward into Ethiopia (Singh and Rana, 1993). In the new world, Chile has long history of lentil cultivation where the crop was introduced by Spanish post-1500 AD. Four wild species of lentils, viz. *Lens orientalis*, *L. nigricans*, *L. ervoids* and *L. montbretii*, reportedly exist in different geographical regions.

### The plant

Lentil is a diploid species with  $2n = 14$ . It belongs to family Leguminosae sub-family Papilionaceae. It is a self-pollinated crop.

Lentil is an annual, herbaceous and short growing legume. It has low-bushy, sub-erect or erect growth habit. Lentil has a slender tap root (up to 36 cm long) with a mass of fibrous lateral roots. The roots carry numerous small round or elongated nodules. The stem is highly branched, thin, weak, slender softly pubescent and ribbed at the angles. The basal part of the stem becomes woody as the plant growth advances. Plant height ranges from 15 to 75 cm (generally



25-40 cm) depending on the genotype and growing conditions. The leaves are alternate, pinnate with 1 to 8 pairs of leaflets. The petioles are short, and the rachis length may range from 1 to 4.5 cm; the rachis may terminate in a simple tendril. The colour of leaves may vary from a light green to bluish green. The leaflets are opposite or alternate, subsessile, narrowly oval-elliptical in shape, 7-25 mm long, 2-7 mm wide, cuneate at the base and rounded to acute at top. The flowers are borne on axillary raceme inflorescence with a slender peduncle, 2-5 cm long. Each peduncle normally bears 1 to 4 flowers. The flowers are small (4-9 mm long). The standard petal may be white, light purplish-blue or white with light purplish-blue veins. The wings and keels are generally white. Pods are oblong, laterally compressed, bulging over the seeds, 6 to 20 mm long and 3.5 to 11 mm wide, rounded to slightly cuneate at the base, short-beaked, glabrous and contain 1 to 2 seeds. The number of pods/peduncle normally varies from one to four. The number of pods/plant may vary from 17 to 500 depending on genotype, plant population and environment.

Lentil seeds are typically lens shaped. The seed diameter ranges from 2 to 9 mm. The 100-seed weight varies considerably ranging from 1.07 to 8.05 g (Saxena and Hawtin, 1981). The testa may be light red, green or greenish red, gray, brown or black. The surface is generally smooth but in some bold types, it may be wrinkled. The cotyledon colour may vary from orange to yellow.

### Varieties

Lentil cultivars are broadly classified as microsperma and macrosperma. The microsperma are small rounded seeds, 2-6 mm in diameter, yellow or orange cotyledons and testa colour ranging from pale yellow to black. Microsperma types are predominantly grown in India, Nepal, Bangladesh, Pakistan, Afghanistan, Ethiopia and Egypt. The macrosperma have large-size seeds (6-9 mm diameter) which are more flattened, yellow cotyledons and pale-green testa. The macrosperma types are concentrated in Mediterranean, Spain, Italy, Greece and North and Latin America.

In India, over 35 varieties of lentil have been released for cultivation in different agro-ecological zones. Most of the varieties are small seeded. In the recent years, however, a few bold-seeded varieties like WBL 58, Lens 4076, K 75, DPL 62, IPL 406 and PL 5 have been developed. Some of the genotypes have resistance/tolerance to rust (Pant L 4076, Pant L 639, DPL 32, Sapna, HUL 57) and wilt (DPL 15, KL 133, Jawahar Lentil 3, VL Masoor 125). Salient features of some of the genotypes which are under seed production programme are given in Table 9.9.

### LATHYRUS (GRASSPEA)

*Lathyrus (Lathyrus sativus L.)* the grasspea or chickling pea is also called *khesari* and *teora* in Hindi, *Kasari* in Bengali and *Kisara* in Nepali. It is a minor pulse crop mostly grown on residual moisture in rice fallows. It is very hardy and versatile crop and thrives well under adverse climatic conditions.

The green leafy part of lathyrus is used as a green fodder and the dried seeds for *dal* preparation. The seeds of lathyrus contain a neurotoxin ODAP

**Table 9.9** Improved varieties of lentil released since 1990, and their salient features

Variety	Sources	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
JL 1	JNKVV	1991	10-15	125	Madhya Pradesh	Tolerant to wilt, seed bold
VL Masoor 4	VPKAS	1991	18.5	168-170	Uttarakhand	Tolerant to rust and wilt, small seed and black
Sapna (LH 84-8)	CCS HAU	1991	21.5	135-140	NWPZ	Tolerant to rust and large seed
L 4076	IARI	1993	21.0	135	NWPZ	Tolerant to rust and large seed
Pant Lentil 4	GBPUAT	1993	22.5	140	NWPZ	Small seed, rust resistant
Priya (DPL 15)	IIPR	1995	22.5	135	NWPZ	Large seed, rust resistant
Garima (LH 82-6)	CCS HAU	1996	15-20	135-140	Haryana	Large seed, rust resistant
Pusa Vaibhav	IARI	1997	17	134	NWPZ	Small seed, rust resistant
Sheri (DPL 62)	IIPR	1997	20-25	135	NWPZ	Large seed, rust resistant
Narendra Masoor 1	NDUAT	1997	17-21	120-130	Uttar Pradesh	Large seed, rust resistant, wilt tolerant
Subrata (WBL 58)	BCKV	1998	12-18	120-125	NEPZ	Large seed, rust tolerant
Jawahar Lentil 3	JNKVV	1999	15-19	115-120	Central Zone	Large seed, wilt tolerant
Noori (IPL 81)	IIPR	2000	17-22	110-120	Central Zone	Large seed, tolerant to rust and wilt
VL Masoor 103	VPKAS	2000	12-14	165	Uttarakhand	Small seed, tolerant to rust
Pant Lentil 5	GBPUAT	2001	15-18	135	Uttar Pradesh and Uttarakhand	Large seed, rust resistant
LLS 699	PAU	2001	14-15	145	Punjab	Tolerant to rust and blight
KLS 218	CSAUAT	2005	14-15	125-130	NEPZ	Small seed, tolerant to rust and wilt
HUL 57	BHU	2005	14-15	130	NEPZ and NHZ	Small seed, tolerant to rust and wilt
Salimar Masoor 1	SKUAST	2005	10-13	120-125	NEPZ	Small seed
LH 89-48	CCS HAU	2005	14-16	140-145	Haryana	Large-seeded, resistant to wilt
VL 507	VPKAS	2006	10-13	160-170	NHZ	Black-seeded, resistant to wilt
VL Masoor 125	VPKAS	2006	15-16	142	NHZ	Black-seeded, resistant to wilt and root rot
VL Masoor 126	VPKAS	2007	10-14	160	NHZ	Small black seed
IPL 406 (Angoor)	IIPR	2008	15-17	120-155	NWPZ	Extra large seed
Pant L 6	GBPUAT	2009	10-18	125-145	Uttarakhand	Small seed
Pant L 7	GBPUAT	2009	10-18	125-145	Uttarakhand	Small seed
Pant L 993	GBPUAT	2009	27		NWPZ	Small seed

NWPZ, North-West Plains Zone; NEPZ, North-East Plains Zone; NHZ, North Hill Zone

Moderately resistant to rust and wilt



( $\beta$ -N-oxalyl-diaminopropionic acid) also known as BOAA ( $\beta$ -N-oxalyl-amino alanine) (Yan *et al.*, 2006) which is a neurotoxin causing lathyrism in human beings on regular consumption. The seeds of lathyrus contain 0.1 to 2.5% ODAP/BOAA.

The dried seeds of lathyrus contain 31.9% protein, 53.9% carbohydrates, 0.9% oil and 3.2% ash.

### Acreeage and production

**World:** At global level, *Lathyrus* is a minor pulse crop. However, in countries like Bangladesh and Nepal, it is a major pulse crop. It is grown in Nepal, Bangladesh, India, Iran, the middle East, South America and South Europe.

**India:** In India, area under lathyrus has progressively decreased due to ban on its trade. Presently, it occupies 0.45 million ha area with annual production of 0.31 million tonnes (Table 9.10). The average productivity is about 698 kg/ha. The major area of lathyrus lies in the states of Chhattisgarh, Maharashtra, Madhya Pradesh, Bihar, Odisha and West Bengal. It is generally cultivated as a relay crop locally called 'paira' or 'utera' (broadcasting lathyrus seeds in standing rice crop 7-10 days before harvesting).

**Table 9.10** Area, production and productivity of lathyrus in India (2009-10)

States	Area ( <sup>'000</sup> ha)	Production ( <sup>'000</sup> tonnes)	Productivity (kg/ha)
Bihar	87	82	944
Chhattisgarh	281	176	625
Madhya Pradesh	43	32	730
Maharashtra	10	4	434
West Bengal	28	20	701
All India	449	313	698

### Origin

*Lathyrus* is known to be the native of Southern Europe and West Asia. It spread as a weed from its original place. The genus *Lathyrus* is distributed in the temperate region of northern hemisphere.

### The plant

The genus *Lathyrus* includes the species *Lathyrus odoratus*. (sweetpea), *L. latifolius* (ever-lasting pea) and *L. sativus* (grasspea). The former two are used for fodder purpose, while the later one is used as a pulse crop. It is a diploid species with  $2n = 14$ .

*Lathyrus sativus* is an herbaceous annual having well developed tap root system. The stem is slender, glabrous, freely branched and procumbently winged. Leaves are alternate, pinnate and terminate in tendrils numbering 3-5. Stipules are prominent and leaf like, ovate and entirely attached to petiole at the base. The leaflets are 2 to 4 in number, linear, lanceolate and sessile. The length of leaflet ranges from 5.5 to 7.5 cm with a width of 1.0-1.3 cm. Inflorescence is axillary raceme with solitary flower of 1.5 cm length. Peduncle



is long and the colour of corolla varies from blue to purple, the keel is white. Stamens are diadelphous, anthers uniform and stigma spatulate. Pods are flat, oblong and up to 4 cm length with two dorsal wings. Normally there are 5 seeds/pod. Seed are wedge shaped, angular, colour ranging from white to brown or mottled. The germination is hypogeal.

### Varieties

Being a minor crop of area-specific importance, the varietal improvement in lathyrus was not well attended. The traditional local land races contain higher concentration of ODAP. Therefore, the major thrust in varietal development programme was laid on high-yielding genotype with lower ODAP (below 1.0 %) content. Consequently a few varieties like Pusa 24, LSD 3 and LSD 6 were released. A major breakthrough in varietal development was achieved in 1996 with release of variety BIO L 212 for NEPZ which contains less than 0.1% ODAP and has high yield potential (15 q/ha). Other high-yielding varieties having low ODAP content and recommended for CZ are Mahateora and Prateek.

### FRENCHBEAN

Frenchbean (*Phaseolus vulgaris* L.), also known as kidney bean, common bean, navy bean, haricot bean and snap bean, is an important grain legume. It is also called *haricos* in French, *judeas* in Spanish, *fagiolini* in Italian, *grünebohnen* in German and *rajmash* in Hindi. In India, the fresh pods used as vegetable are called *faras* beans and the dried pods for pulse is called *rajmash*. The more fleshy tender pods of round-podded types with less string are preferred for vegetables as compared to flat pods. The dried seeds are cooked as a whole with spices as a special dish or canned in sauce.

Dried seeds of Frenchbean are highly nutritious containing 22.9% protein, 1.3% fat, 60.6% carbohydrates and minerals, viz. calcium (260 mg/100 g seed), phosphorus (410 mg/100 g seed) and iron (5.8 mg/100 g seed).

### Area and production

**World:** Frenchbean is cultivated in a variety of environmental conditions ranging from sea level to highlands in the temperature range of 20-25°C. It is extensively grown in five major continental areas of Eastern Africa, North and Central America, South America, Eastern Asia and western and South-eastern Europe. Globally, Frenchbean occupies 28.2 million ha area with an annual production of 18.95 million tonnes. Amongst the Frenchbean-producing countries, Brazil ranks first in area and production. Other important Frenchbean-producing countries are Angola, Burundi, Cameroon, Rwanda, Tanzania, Uganda and Zaire in Africa; Mexico, USA and Canada in North America; Colombia in south America; Turkey, China and India in Asia; and Romania, Portugal, Spain and Italy in Europe.

**India:** In India, Frenchbean is only a minor pulse crop. It is generally cultivated during *kharif* (monsoon) season on hills. However, with the development of new genotypes, the crop has been introduced in north-east plains and central zone as a *rabi* crop. The important states are Uttar Pradesh, Bihar,



Gujarat and Maharashtra. At present there is no record of area under winter sown crop. The area and production of *kharif* sown Frenchbean is about 98,000 ha and 1,000 tonnes respectively.

### Origin

Frenchbean has been in cultivation since ancient times, more than 400 cultivars of this crop are known in the world. Frenchbean has evolved from a wild-growing vine distributed in the highlands of middle America and Andes over a period of 7,000-8,000 years. The genus *Phaseolus* consists of 50 species, all of which are distributed in Americas. Based on the observations made on archaeological remains from Peru and south western United States it was concluded that the common bean had originated in the Americas. Vavilov (1951) reported the primary centre of origin of *Phaseolus* in South Mexico and Central America and secondary centre of origin in Peruvian-Ecuadorian-Bolivian region of South American continent.

### The plant

Frenchbean belongs to subfamily Papilionaceae of family leguminosae. It is a diploid species with  $2n = 22$ . The Frenchbean is a self-pollinated crop.

Cultivated Frenchbean is annual, herbaceous determinate or indeterminate in growth. Stem has elongated internodes and may produce 30 or more nodes before it is terminated by an inflorescence. Stem is erect and bushy in nature. The main axis produces less than 10 nodes. Internodes are usually short. It has well developed tap root system with profuse lateral roots. Leaves are alternate, trifoliate, somewhat hairy, petiole long with groove on upper side and well-developed pulvinus at base. Stipules are small ovate and acute. Stipels minute and lanceolate. Leaflets are ovate and acuminate up to a size of 15 cm × 10 cm. The lateral leaflets are assymmetrical. Inflorescence is a raceme bearing 2-3 flowers. Flowers are zygomorphic with a bipetalled keel, two lateral wing petals and a large outwardly displayed standard petal. Flower colour may be white or purple. The peduncle is short, pedicels less than 1 cm long, calyx are bracts, leafy, ovate, 4 mm long with 1 upper and 3 lower teeth. The colour of corolla may be white, cream, pink or violet, 1-1.5 cm long, keel coiled. Stamens diadelphous (9+1), anthers uniform and oblong. The style is coiled with introrse stigma.

Pods are usually slender and narrow. The size of pod may be up to 20 cm × 1.5 cm. The number of seed/pod is usually 5-7. However, some genotypes produce 10 seeds/pod. Pods are yellow or green with or without anthocyanin fleck or blotches.

Seeds are oblong, globular or kidney shaped, and are variable in colour, shape and size. The colour may be white, yellow, pink, red, purple, brown, buff or black. Self coloured or with super-imposed patterns of flecks. Hilum may be ringed with a different colour having a length of 0.7-1.6 mm.

### Varieties

In India the first ever documented variety of Frenchbean is VL 63 which was developed at the Vivekanand Parvatiya Krishi Anusandhan Shala (VPKAS),



Almora. In Frenchbean, the development of variety is oriented towards the seed size and seed colour. Generally, the bold seeded varieties having variegated colour are preferred by the consumers.

Systematic varietal development of Frenchbean for winter cultivation started in early eighties. Since then many varieties such as Uday, HUR 15, HUR 137, Amber, Utkardh, Arun etc. have been released for cultivation. The important genotypes with their salient features are given in Table 9.11.

**Table 9.11** Improved varieties of Frenchbean (*rajmash*) released since 1990, and their salient features

Variety	Source	Year of release	Yield (q/ha)	Days to maturity	Area of adoption	Characteristics
Malviya Rajmash 137	BHU	1991	18	120	NEPZ	Red seed
HPR 35	HPKVV	1992	15	73	Maharashtra	Red seed with purple streaks
IIPR 96-4 (Amber)	IIPR	2002	15-16	139	NEPZ	Resistant to BCMV
IIPR 98-5 (Utkarsh)	IIPR	2005	17	122	NEPZ	Tolerant to BCMV
IIPR-98-3-1 (Arun)	IIPR	2007	16	120	Central Zone	Tolerant to BCMV, Gulf red seed

BCMV, Bean common mosaic virus; NEPZ, North-Eastern Plains zone

## SOILS

In India, *rabi* season pulses are grown on a variety of soils ranging from sand dunes in Rajasthan to deep Vertisols in Maharashtra. A well-drained, deep soil free from excessive soluble salts with pH 6.0 to 8.5 and soil texture sandy loam to sandy clay loam is considered ideal for chickpea, lentil, field pea and Frenchbean. *Lathyrus* could be successfully grown on heavy-textured soils suitable for rice. All the cool-season pulses are highly sensitive to salinity and sodicity. Among various crops, Frenchbean is the most sensitive to salt stress and sodicity followed by lentil, peas and chickpea.

## SEEDBED PREPARATION

Pulses generally do not need fine seedbed. However, Frenchbean with bold seeds and hard seed-coat needs good seedbed. Seedbed preparation is accomplished through primary tillage which consists of ploughing, harrowing, discing, bakharing, planking etc. A good seedbed should have friable but compact soil, adequate moisture and should be free from weeds and plants debris.

Tillage requirements depend on soil type, moisture content, preceding crops, planting methods, weed infestation and the target crops. Generally, one deep ploughing followed by cross harrowing and planking ensures good seedbed. Since winter pulses excepting Frenchbean, are generally grown on residual moisture under rainfed conditions, efforts should be made to conserve



late monsoon showers. On heavy soils of central and south India, a rough seedbed is considered ideal for chickpea as it allows better aeration and avoids soil compaction with winter rains.

On light-textured soils of north India, frequent shallow cultivations (2-3) late in the evening to expose more surface area to capture dew during early winter season and planking next morning is generally practiced under rainfed conditions. Considering energy cost, tillage should be minimized.

Under monocropping system when the land is kept fallow during monsoon season, deep tillage at the beginning of rains and 1-2 light cultivations before withdrawal of monsoon help in increasing profile moisture. Under double-cropping system, the land preparation is generally done with pre-plant irrigation if moisture content in the top soil layer after harvest of preceding crop is not adequate for germination of winter crop. When chickpea is grown after rice, a deep ploughing followed by cross harrowing is necessary but after maize, sorghum, oilseeds etc., cross harrowing is generally adequate.

Under *utera* system (relay cropping) of cultivation of lathyrus and lentil, no tillage is done. However, when planting is done after the harvest of rice, one deep ploughing followed by cross harrowing and planking is necessary. Kumar and Ali (1995) found that the yield of lentil, lathyrus and chickpea considerably increased when planted after land preparation as compared to zero tillage under relay planting in rice under Kanpur conditions.

To avoid incidence of termites and cutworms which generally pose serious threat on light-textured soils of north India, soil application of carbaryl dust @ 20-25 kg/ha should be done at the time of last ploughing/harrowing.

### SEED AND SEED TREATMENT

Quality seed is the key to plant establishment and crop productivity. The seed should be genetically and physically pure with 90-95% viability, free from disease and physical damage. Prolonged and faulty storage decreases seed viability. High moisture and temperature are conducive for poor viability of seeds. Generally bold-seeded pulses like Frenchbean and *kabuli* chickpea lose seed viability rapidly on storage beyond one year. Of a given cultivar, large and too small seeds should not be used for planting as their viability and seedling vigour are, respectively, poor. The germination of seed and plant establishment are considerably influenced by quality of seed, sowing depth, soil-moisture content, soil temperature, physico-chemical properties of soil, seedling vigour, etc.

Pulse seeds should be treated with systemic fungicides like carbendazim, thiram, captan, brassicol etc. to control seed-borne diseases. Normally, 2-3 g fungicide/kg seed is recommended. Fungicidal treatment should be done at least 3 days before sowing. In areas where termite incidence is commonly observed, seed treatment with an appropriate insecticide solution is quite effective.

The seed treatment of legumes is also done with *Rhizobium* culture to capitalize on their intrinsic capability and potentiality to trap atmospheric nitrogen in the root nodules through BNF. It is estimated that annual biological nitrogen fixation (BNF) is about 175 million tonnes of which close to 79% is accounted for by terrestrial fixation.



The free living rhizobia infect the host legumes through infection thread at the point of emergence of lateral roots, and are transformed into bacteroids which are the sites for  $N_2$  fixation. The nitrogen fixation is governed by the host, microsymbiont, physical and chemical properties of soil, soil moisture and nutrient status, soil microflora and environmental factors. Not only legume species differ in nodulation but cultivars within a species also differ significantly, suggesting thereby that the host factors are important determinants of nodulation.

Moisture stress as well as excess moisture (waterlogging) adversely affect rhizobial population and BNF. Poor BNF under waterlogged conditions is due to anoxia (lack of oxygen). Deficiency of essential plant nutrients specially phosphorus and molybdenum appreciably decreases BNF. Molybdenum is an integral component of nitrate reductase enzyme and therefore its deficiency directly influences the BNF. Increasing soluble salt and extremes of soil pH reduce BNF. However, *Rhizobium* have high degree of tolerance to soil salinity and alkalinity than the host plant.

Field survey conducted in different agro-ecological zones of India during 1991-93 showed that native population of *Rhizobium* was low to medium in 86% of samples collected from chickpea fields. The corresponding figures for lentil, peas and lathyrus were 73, 85 and 75%. This emphasizes the need for seed inoculation with appropriate *Rhizobium* culture. In frontline demonstrations conducted during 2002-07 at various locations in different states, the yield gain owing to seed inoculation in chickpea was up to 20% over control (Table 9.12). Several multilocational studies conducted under AICPIP revealed that inoculation increased grain yield of winter pulses by 10-15% (Ali, 1998). Depending on rhizobial population, level of crop management, edaphic conditions and prevailing environmental factors, chickpea, lentil, peas and fababean can fix 41-270 kg, 62-103 kg, 30-140 kg and 121-171 kg N/ha respectively (Sekhon *et al.*, 1990).

The seed inoculation process is very simple. The inoculation should be done 10-12 hr before sowing. To inoculate 10 kg seeds, add 100 g gur [gaggery (brown sugar)] and 2 g gum arabica to one litre water and heat up for about half an-hour to prepare a homogenous mixture. Allow the solution to cool at room temperature and then add one packet of culture to it and mix up thoroughly. Rub this mixture of the culture solution on seeds to get a uniform

**Table 9.12** Effect of seed inoculation with *Rhizobium* on grain yield of chickpea in frontline demonstrations (2002-07)

States	No. of front-line demonstrations	Inoculation	Control	Increase over control (%)
Gujarat	20	725	705	2.8
Maharashtra	10	1,428	1,240	15.1
Madhya Pradesh	4	1,935	1,669	16.2
Rajasthan	45	1,180	1,060	11.3
Uttar Pradesh	6	1,722	1,428	20.5

Source: IIPR (2007)



thin coating all over. Dry the seeds in shade for about 1 hr and sow thereafter. Since the *rhizobia* are crop-specific, only right type of culture meant for the specific crop should be used. Cowpea group *Rhizobium* is effective against chickpea, lentil and lathyrus, whereas *R. leguminosarum* is specific to pea. For Frenchbean, effective *Rhizobium* strains are not available yet. Fungicides like captan, thiram, bavistin, etc., are compatible with *Rhizobium* culture.

Seed dressing with fungicides should be done at least 2-3 days before culture treatment.

In view of escalation in price of P fertilizers, the need for dual inoculation, i.e. *Rhizobium* and phosphate-solubilizing micro-organisms (PSM), is gaining importance. *Bacillus polymixa* and *B. megaterium* cultures are being commercially produced for inoculation. The PSB produce organic acids which decrease soil pH and thus accelerate dissolution of insoluble phosphates which become available to crop plant. The *Rhizobium* and PSB cultures can be mixed together for seed treatment. Singh and Sharma (2011) observed beneficial effect on grain yield of chickpea with application of PSB and *Rhizobium* along with 40 kg P<sub>2</sub>O<sub>5</sub>, the order of response being 81 and 103 kg/ha. Seed pelleting with nutrient solutions especially micronutrients is also reported beneficial in areas deficient in that nutrient.

The symbiotic association between plant roots and mycorrhizal fungi has received greater attention in recent years. The vesicular arbuscular mycorrhiza VAM enhances plant growth by improved mineral nutrition particularly P and water uptake on account of the hyphal network originating from mycorrhizal roots which make close contact with the soil mass. Rao *et al.* (1986) observed higher N and P concentration in shoots of chickpea due to *Glomus fasciculatum* inoculation which was almost equivalent to the effect of seed inoculation with *Rhizobium*. Reddy (1992) reported that both *Rhizobium* and VAM inoculation improved number of nodules, dry weight of nodules, and seed yield in lentil and were at par with each other (Table 9.13). Dual inoculation with *Rhizobium* and VAM further increased nodulation and yield.

The sequence of seed treatment should start with insecticide followed by fungicide and microbial culture. The insecticides like aldrin and fungicides such as carbendazim, thiram and captan are compatible with *Rhizobium* culture.

**Table 9.13** Effect of biofertilizers on root nodulation at 80 days after sowing on grain yield of lentil during 1989-90

Treatments	Nodules/plant	Dry weight of nodules (mg/plant)	Grain yield (tonnes/ha)
Uninoculated control	17.4	4.2	0.84
<i>Rhizobium</i>	26.1	5.4	1.03
VAM	20.5	6.3	1.09
<i>Rhizobium</i> + VAM	29.8	7.2	1.19
LSD (P = 0.05)	NA	NA	0.04

VAM, Vesicular arbuscular mycorrhiza

Source: Reddy (1992)



### PLANTING TIME AND METHOD

Planting time is the most important non-monetary input having profound effect on crop growth, phenological development, occurrence of pests and crop productivity. The plant environment such as temperature, photo-period, moisture availability (in dryland area), etc. is significantly changed with the time of planting. It also influences availability of plant nutrients, BNF and weed infestation.

Planting time is generally dictated by environmental temperature. However, in rainfed areas where soil moisture is the major constraint for seed germination and plant establishment, the availability of moisture in surface layer also plays key role besides temperature. The optimum time of planting differs from location to location, and also within same location depending on the cropping systems in which pulses are grown.

Early as well as delayed planting decreases yield of winter pulses. Early planting induces excessive vegetative growth on account of high temperature and humidity and poor pod set. Seedling mortality due to high temperature is also commonly observed in central India. The delayed planting restricts vegetative growth and pod bearing branches, decreases BNF and may also lead to forced maturity as well as increased incidence of pest (*Helicoverpa*), particularly in chickpea (Ali *et al.*, 1998).

In dryland areas, early planting is a thumb rule rather than exception. Further, the short-duration genotypes have advantage over late-maturing ones for late planting. Chickpea genotypes PBG 1, Uday and Pusa 372 can be planted up to mid-December.

The optimum time of planting chickpea in north India is the second fortnight of October under rainfed conditions and the first fortnight of November under irrigated conditions. Delay in planting by 4 weeks beyond optimum period caused yield loss to the tune of 30-35 kg/ha/day (Ali, 1998). In the central and south India, first fortnight of October is the optimum period under rainfed conditions and the second fortnight under irrigated conditions (Table 9.14). Field studies conducted at Ludhiana during 1991-93 showed that planting beyond 5 November caused significant reduction in nodule dry weight and leghaemoglobin content (Sharma *et al.*, 1995).

Multilocation studies under AICPIP on planting dates of lentil showed that end of October was the optimal period in NWPZ whereas in NEPZ second

**Table 9.14** Grain yield (kg/ha) of irrigated chickpea as influenced by planting dates in different agro-ecological zones

Planting date	Zones		
	NWPZ (Ludhiana)	NEPZ (Dholi)	CZ (Badnapur)
10 October	1,237	1,560	1,499
25 October	1,399	1,950	1,817
9 November	742	1,920	1,536
24 November	625	980	1,320

Source: AICPIP (1983-86)



fortnight of November was optimal subject to adequacy of moisture at planting (Table 9.15). The yield declined at the rate of 14.8 kg/ha/day in NWPZ and 30 kg/ha/day in NEPZ when planted beyond end of December (Ali, 1985). In the Central zone where moisture is the major constraint, an early planting by mid October is ideal to ensure proper germination.

**Table 9.15** Effect of planting dates on seed yield (tonnes/ha) of lentil in different agro-ecological zones

Planting date	NWPZ (Pantnagar)	NEPZ (Kalyani)
30 October	1.95	1.60
14 November	1.72	1.61
29 November	1.50	1.29
14 December	1.28	0.56
29 December	0.71	0.03
LSD ( $P = 0.05$ )	0.19	

Source: Ali (1985)

In *utera* system, planting time largely depends on cessation of monsoon rains and maturity of rice crop. In lowlands, water from rice field is drained by the end of September or early October and lentil/lathyrus seeds are broadcast 4-7 days before harvest of rice.

The optimum time of planting fieldpea and Frenchbean which are generally sown with a pre-plant irrigation and follow a regular *kharif* crops, lies between the end of October and first fortnight of November. Ali (1989a,b) reported that ideal time of planting Frenchbean in central Uttar Pradesh was from mid-October to first week of November. Genotypic variation with respect to planting date was also observed. The optimum time for early-duration varieties like VL 63 and HUR 137 was end of October, whereas for late maturing variety PDR 14 it was extended up to mid-November. Studies under AICPIP showed that the optimum time of planting in Bihar (Dholi) was second fortnight of November and in Vidarbha region of Maharashtra mid-October.

In Central zone where growth period of winter pulses is restricted due to high temperature and low profile moisture, early planting is generally advantageous. Singh *et al.* (1996) working at Ambikapur (Madhya Pradesh) found that planting of fieldpea in the first week of October produced 2,225 kg/ha as compared to 1,292 kg/ha from mid-November planting.

### PLANT POPULATION, SEED RATE AND PLANTING METHOD

Adequate plant stand is the basic pre-requisite for higher productivity. In non-tillering crops like pulses which have low compensatory ability to make up for per plant yield loss, maintenance of optimum plant stand is all the more important. Further, in rainfed areas where winter pulses are predominantly grown on residual moisture, low productivity is often associated with poor plant stand. Efforts to maintain higher plant stand under these conditions leads to increased inter- and intra-plant competition for moisture and nutrients which



are scarce, and thus it proves counter-productive. It is therefore, imperative to establish optimum plant stand to harness maximum from natural and applied production resources.

### Plant population

Plant population is generally determined by growth pattern and canopy structure of a cultivar, planting time, growing conditions and the cropping systems. Genotypes with low canopy growth need higher plant density than those with vigorous growth. Similarly, under late planting conditions, the optimal plant stand would be higher than a normal planted crop due to restricted growth in the former case. Adequate moisture and nutrients enhance vegetative growth and therefore, a low plant stand is desirable under such conditions. Multilocation studies under AICPIP have shown that the optimum plant density of timely sown chickpea under rainfed conditions was 33 plants/ m<sup>2</sup> (30 cm × 10 cm) whereas for late planting (December) in irrigated areas an increased density of 44 plants/ m<sup>2</sup> (25 cm × 10 cm) was ideal (Ali, 1988; Dhingra *et al.*, 1986). In the irrigated areas of NWPZ where chickpea duration generally extends up to 150-160 days, 22 plants/ m<sup>2</sup> (45 cm × 10 cm) proved ideal as against 33 plants/m<sup>2</sup> in the NEPZ (Table 9.16).

**Table 9.16** Effect of row spacing on the yield of chickpea in different zones (1989-90 and 1990-91)

Zones/Locations	Row spacing (cm)	
	30	45
<b>NWPZ</b>		
Hisar	1,211	1,278
Ludhiana	973	989
<b>NEPZ</b>		
Varanasi	1,691	1,541
Kanke	980	859
<b>CZ</b>		
Badnapur	1,512	1,388
Junagadh	2,407	1,759
Rahuri	1,445	1,302
Sehore	1,166	1,039

Plant to plant spacing 10 cm; NWPZ, North-western Plains Zone; NEPZ, North-eastern Plains Zone; CZ, Central Zone

Source: AICPIP (1989-90 and 1990-91)

### Seed rate

Seed rate is the key determination of plant population. Seed rate is decided on the basis of seed size, seed purity and germination percentage. Pulse genotypes have great variation in seed size and therefore, the seed rate of a given crop varies to a great extent for similar production system. For instance, the seed size of chickpea genotypes varies from 12 to 30 g/100-seed weight. In lentil, the seed weight of microsperma type is 1.5-2.5 g/100-seed as compared to macrosperma types having more than 3 g/100-seeds. Planting method has also significant influence on seed rate. In broadcast method of sowing, seed rate is kept higher than row planting on account of uneven distribution and poor germination of seeds in the former case. In broadcast method, many seeds do not get properly placed in the moist soil layer and are also liable to bird damage. Yields are generally higher in row planting than broadcast owing to better plant establishment and minimum inter- and intra-plant competition. The optimum



seed rate for bold-seeded (25 g/100-seed weight) chickpea genotypes like Pusa 256, Phule G 5 etc. is 80-85 kg/ha, whereas for small-seeded (15-18 g/100-seed weight) it is 50-60 kg/ha. Under late planting, the seed rate should be increased by 20-30% over normal seed rate. The optimum seed rate of microsperma lentil is 40-45 kg/ha, whereas for macrosperma it is 55-60 kg/ha. Under *utera* planting where microsperma genotypes are generally grown, an increased seed rate of 60 kg/ha is recommended. In fieldpea, 50-60 kg/ha seed rate for small-seeded genotypes (13-16 g/100-seed weight) and 80-90 kg/ha for bold-seeded (20 g/100-seed weight) has been found optimal. On account of larger seed size (35-45 g/100-seed weight) of frenchbean, its seed rate is 120-140 kg/ha. The recommended seed rate of lathyrus is 60-80 kg/ha despite its smaller size as in broadcast sowing under *utera* system, the germination is usually very poor due to lack of better contact of seeds with moist soil.

### Planting method

It is an important management factor which has direct effect on seed requirement, plant establishment, performance of cultural operations and efficiency of production inputs. Planting of winter pulses is done by: (i) broadcasting seeds in well-prepared seedbed, followed by planking, (ii) drilling seeds manually in furrows opened by *desi* plough with or without attachment of seeding tube (*pora*), (iii) seeding through tractor or bullock-operated seed drills, and (iv) broadcasting seeds (lentil, lathyrus) in standing rice crop without tillage operation, in different parts of the country depending on initial soil moisture, irrigation facilities, available farm implements and cropping systems. Line sowing is beneficial over broadcast, as it ensures uniform distribution of seeds, placement of seeds at proper depth, better plant stand, ease in cultural operation and also improved drainage. It allows successful intercropping and high return. Relay cropping, which involves broadcasting seeds of pulses in standing rice crop, is a conventional method with huge loss of seeds. However, at present no improved method of planting has been developed under these situations. Row orientation also influences growth and yield of winter crops. North-south row orientation is generally beneficial over east-west orientation, as in the former case there is better interception of light in crop rows. In the recent year, raised bed planting has shown great promise as it reduces water requirement, promotes better aeration and ultimately gives higher yield. Generally, 0.75- 1.0 m wide raised bed are made through raised bed maker to accommodate 3-4 rows of chickpea/pea. Raised bed planting of chickpea increased grain yield by 315 kg over flat bed at Kanpur (Table 9.17).

**Table 9.17** Effect of planting methods on grain yield of chickpea

Planting method	Grain yield (kg/ha)	
	2005-06	2006-07
Flat bed	1,840	2,010
Raised bed	2,150	2,030
CD (P = 0.05)	110	160

Source: Pramanik *et al.* (2009).

### Depth of sowing

Seeding depth considerably influences seed germination and emergence. The effect of seeding depth is more important in dryland areas where crops are



raised on conserved moisture. Deeper seeding may cause poor emergence, and shallow depth may lead to poor germination on account of low soil moisture in the surface layer. Germination of most of the cool-season pulses is hypogeal and therefore they can be planted relatively at deeper depth depending on availability of adequate moisture. In rainfed areas, deep sowing (10 cm) of chickpea proved better than shallow depth (5 cm). Further, deep planting reduces incidence of *Fusarium* wilt as compared to shallow planting and also promotes better root development (Kaul *et al.*, 1974). In areas where moisture content in top soil layer is low, seeds are placed in deepest zones without planking. In the sand dunes of Rajasthan, chickpea seeds are sown as deep as 30 cm. In dryland areas, it is a common practice to attach a funnel (*pora*) to the V-shaped country plough to place chickpea seeds at a depth of 10-12 cm.

### NUTRIENT MANAGEMENT

Adequate and balanced supply of nutrients holds the key of successful crop production. The philosophy of fertilizer management encompasses putting the right amount of nutrients at right time through an appropriate method so as to minimize their losses, thereby making their most efficient use for enhancing the crop productivity and maintaining or enhancing the soil fertility and productivity.

In plant-soil-environment continuum, plant roots absorb mineral nutrients and water and in presence of light and CO<sub>2</sub>, carbohydrate is synthesized which in turn is utilized in various metabolic processes for further growth and development.

All the 17 essential nutrients are required in balanced proportion for optimum growth and development of plant. However, in terms of significance, the amount of nutrients required for a group of crops varies depending on the growth cycle, the biochemical composition of the ultimate products and the capacity of the crop plant to assimilate atmospheric nitrogen (biological nitrogen fixation). Pulses require less of nitrogen, as they are capable of fixing atmospheric nitrogen through root nodule-rhizobia symbiosis but need adequate phosphates and sulphur for their better root proliferation and synthesis of sulphur-containing amino acid respectively. Further, they require more of some of the micronutrients like molybdenum which is an integral constituent of the nitrogenase, an enzyme essentially required for nitrogen fixation.

The fertilizer requirement of *rabi* pulses varies depending on the initial soil fertility conditions, moisture regimes, genotypes, growth and yield of the crop, residue recycled, etc. Further, the preceding crop also significantly influences the nutrient requirement of the winter pulse. In general, the winter pulses remove about 30-50 kg N, 2-7 kg P<sub>2</sub>O<sub>5</sub>, 12-30 kg K<sub>2</sub>O, 3-10 kg Ca, 1-5 kg Mg, 1-3 kg S, 200-500 g Mn, 5 g B, 1 g Cu and 0.5 g Mo for producing one tonne of biomass.

As pulses are rich source of protein they remove fairly good amount of nitrogen from soil of which major fraction is met through biological nitrogen fixation. However, for an early head start a starter dose of 10-15 kg N/ha is essential for almost all the crops except Frenchbean, which requires 100-120



kg N/ha because of its poor nodulation in the plains of northern India, thus making them dependent on applied nitrogen. In terms of significance, phosphorus is most indispensable mineral nutrient for pulse crops, as it helps in better root growth and development and thereby making them more efficient in BNF fixation. Another nutrient which has shown great promise, is sulphur. Application of sulphur increased the productivity of most of the pulses by 20-28% (Tandon, 1991).

Amongst micronutrients the response to Zn, B and Mo application has been observed in many pockets. The response of zinc application is very much pronounced under lowland rice production system whereas the boron application has shown conspicuous effect on calcareous soils of Bihar and light-textured soils of south Rajasthan (AICPIP, 1992-95). The molybdenum application has shown promising effect in chickpea on Vertisols (AICPIP, 1995-97).

Application of various fertilizers should be recommended only on the basis of soil test. However, in absence of soil-fertility status data, application of following amount of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and S is recommended on the basis of response obtained in trials under AICPIP in various parts of the country under diverse agroclimatic conditions (Table 9.18). Crop response to different plant nutrients is discussed here.

**Table 9.18** Recommended dose of nutrients for different *rabi* pulses

Crop	Eco-system	Planting time	Dose (kg/ha) N-P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O-S
Chickpea	Rainfed	Normal	20 - 40 - 0 - 20
	Irrigated	Normal	20 - 60 - 20 - 20
		Late-sown	40 - 40 - 20 - 20
Lentil	Rainfed	Normal	20 - 40 - 0 - 20
	Irrigated	Normal	20 - 40 - 0 - 20
		Late sown	30 - 40 - 0 - 20
Fieldpea	Rainfed	Normal	20 - 40 - 0 - 20
	Irrigated	Normal	40 - 40 - 20 - 20
		Late sown	40 - 40 - 20 - 20
Frenchbean	Irrigated	Normal	100 - 60 - 20 - 20
Lathyrus	Rainfed ( <i>paira/utera</i> cropping)	Normal	10 - 30 - 0 - 0

### Chickpea

**Nitrogen:** In general, chickpea has shown response to application of stater dose of nitrogen up to 15-20 kg/ha. The response to applied nitrogen varies from 8.5 to 19.5 kg grain/kg nitrogen applied depending on soil conditions and crop growth. However, response to nitrogen is poor under well-developed nodulation with efficient biological nitrogen fixation system. Under late-sown conditions, the crop responds well up to 40 kg N/ha. Under rainfed conditions, foliar spray of 2% urea or diammonium phosphate (DAP) at podding stage has proved beneficial in different agro-ecological regions.

**Phosphorus:** Conspicuous response to phosphorus application in chickpea has been observed by several workers (Dev, 1987; Prabhakar and Saraf, 1991).



The response is more distinct under irrigated conditions than under rainfed conditions (Parihar, 1990). In most of the cases, response to 40-60 kg  $P_2O_5$ /ha has been observed both at farmers' field and research stations (Table 9.19). Under rainfed conditions, the moisture content in the soil profile determines the response of applied phosphorus. However, generally chickpea has been found to respond up to 30-40 kg  $P_2O_5$ /ha.

**Table 9.19** Effect of levels of phosphorus and zinc on seed yield of chickpea (kg/ha)

Treatments	Locations				Mean
	Durgapura	Khargone	S.K. Nagar	Varanasi	
<b>Phosphorus (kg <math>P_2O_5</math> /ha)</b>					
0	1,971	1,380	1,546	1,679	1,644
30	2,104	1,915	1,701	2,123	1,961
60	2,190	2,124	1,741	2,124	2,045
<b>Zinc (kg <math>ZnSO_4</math> /ha)</b>					
0	2,057	1,737	1,599	1,762	1,789
25	2,119	1,875	1,726	1,984	1,926

Source : AICPIP (1991)

The response to applied phosphorus, is determined by several factors such as method of application, source of phosphorus, profile moisture content etc. Deep band placement of phosphorus (15 cm) on heavy soils (black clay) was found advantageous than mixing it in soil (Arihara *et al.*, 1991). Amongst various sources of P, single super phosphate has been found more effective than DAP (AICPIP, 1991). Phosphate-solubilizing bacteria (PSB) have been found effective in increasing the efficiency of applied phosphorus (Table 9.20). Prabhakar and Saraf (1991) found application of 40 kg rock phosphate with PSB comparable with 40 kg  $P_2O_5$ /ha through single superphosphate.

**Potassium:** The response of chickpea to potassium application is generally low, as most of the soils in chickpea-growing areas are medium to rich in available potassium. However, the response of applied K has been recorded in laterite, red, coastal and deltaic alluvium soils of India. Application of 20 kg  $K_2O$ /ha is recommended under deficient soil conditions.

**Sulphur:** On S-deficient soils, the response to sulphur has been found in the range of 20-60 kg S/ha (Aulakh and Pasricha, 1986). Due to increased

**Table 9.20** Grain yield of chickpea as affected by inoculation with *Rhizobium* and phosphate solubilizing micro-organisms (PSM)

Treatment	Nodule dry weight (kg/plant)	Grain yield (kg/ha)
T <sub>1</sub> , Control	75	1,470
T <sub>2</sub> , 40 kg $P_2O_5$ /ha through DAP	93	2,109
T <sub>3</sub> , T <sub>2</sub> + <i>Rhizobium</i>	100	2,212
T <sub>4</sub> , T <sub>3</sub> + PSM	102	2,293
CD (P=0.05)	4.3	33

Source: Singh and Sharma (2011)



cropping intensity under north Indian conditions and use of high-analysis fertilizers, the deficiency of sulphur is getting apparent in most of the soils. In multilocal studies carried out during 1991-94 under AICPIP, the mean response of chickpea to 20 kg S/ha was 583, 288, 383 and 273 kg/ha in NWPZ, NEPZ, CZ and SZ respectively (Table 9.21). Significant response up to 40 kg S/ha was also observed in Central zone (Ali and Singh, 1995). At Hisar (Haryana) application of 40 kg S/ha increased grain yield by 225 kg/ha and also the water-use efficiency (Singh *et al.*, 2004). Various sources of sulphur like gypsum, SSP, pyrite and elemental sulphur were found equally effective (Ali and Singh, 1995; Ram and Dwivedi, 1992).

**Micronutrients:** Amongst micronutrients, the significant response to application of Zn, B, Mo and Fe have been found at many locations (AICPIP, 1990-93). Yield gain of 320 kg/ha with the application of 25 kg zinc sulphate has been observed (Takkar and Nayyar, 1986). The significant impact of boron and molybdenum application have also been observed. Soil application of 10 kg borax/ha and ammonium molybdate @ 1.5 kg/ha increased yield to the tune of 306-450 kg/ha (Ali and Mishra, 1996).

**Table 9.21** Response of chickpea to levels and sources of sulphur

Treatment	Grain yield (kg/ha)			
	NWPZ	NEPZ	CZ	SZ
<b>Chickpea</b>				
<i>Sulphur (kg/ha)</i>				
0	1,213	1,632	1,859	1,033
20	1,796	1,920	2,242	1,306
40	1,699	2,091	2,528	1,386
<i>Source of sulphur</i>				
Gypsum	1,744	1,988	2,277	1,441
Elemental S	1,621	1,844	2,254	1,207
Single super phosphate (SSP)	1,633	1,917	2,608	1,456
<b>Lentil</b>				
<i>Sulphur (kg/ha)</i>				
0	1,226	810	—	—
20	1,818	1,117	—	—
40	1,697	1,230	—	—

### Lentil

For producing one tonne of seed, the lentil on an average removes 50 kg N, 14 kg P<sub>2</sub>O<sub>5</sub>/ha and 78 kg K<sub>2</sub>O/ha, indicating the need for adequate supply of these nutrients along with other major- and micro-nutrients through judicious fertilizer application to ensure good seed yields.

**Nitrogen:** Studies on nitrogen management indicated that under good symbiotic association, approximately 85% of the total nitrogen requirement of the crop is fulfilled by biological nitrogen fixation. Hence in the presence of natural rhizobia or introduced inoculation, the response to applied nitrogen is poor. However, on sandy soils with low organic matter content, the response to applied nitrogen to the tune of 10-25 kg/ha has been obtained (Bhandari *et al.*, 1989).



**Phosphorus:** The soils of many lentil-growing areas are poor in available phosphorus content. Response to applied phosphorus has been observed on low-P soils and the optimum level ranges from 30 to 60 kg  $P_2O_5$ /ha depending on available P in the soil and its P-fixing capacity. Phosphorus application is equally important under rainfed conditions, mainly due to three reasons firstly, the growth and proliferations of roots would enable the plants to extract the moisture from deeper layers; secondly, improved supply of P might reduce the transpiration ratio; and thirdly, raising concentration of soluble P in the moisture film increases the P supply to plant roots under restricted moisture conditions. Multi-location studies under AICPIP during 1985-89 showed that lentil responded well to 18 kg N, 46 kg  $P_2O_5$  and 20  $K_2O$ /ha in all the zones, the order of response being higher for P (Table 9.22).

A direct contact with phosphatic fertilizers and lentil seed is harmful as it hampers the seed germination. Side banding 2 cm below the seed is the ideal way of application of phosphatic fertilizers in lentil. Moreover, placement reduces P fixation in the soils of high pH and calcium activity.

**Table 9.22** Effect of fertilizer on seed yield (tonnes/ha) of lentil

Treatments	Agroecological zones		
	NWPZ	NEPZ	CZ
Control (no fertilizer)	1.32	0.78	0.62
18 kg N/ha	1.47	0.87	0.72
46 kg $P_2O_5$ /ha	1.51	1.08	0.81
18 kg N + 46 kg $P_2O_5$ /ha	1.53	1.19	0.94
20 kg $K_2O$ /ha	1.35	1.01	0.74
18 kg N + 46 kg $P_2O_5$ /ha + 20 kg $K_2O$ /ha	1.48	1.14	0.90
20 kg S/ha	1.46	-	0.66

Source: AICPIP (1985-89)

**Potassium:** Only at a few locations, positive responses to potassium application in lentil has been reported as soils of the most of the lentil-growing areas are rich in available potassium. A significant increase in the grain yield of lentil was observed on a sandy-loam soil up to 22 kg  $K_2O$ /ha (Sharma, 1970).

**Sulphur:** Like other cool-season food legumes, lentil yield could be limited due to shortage of available sulphur in soil. The multi-location studies conducted under AICPIP in NWPZ revealed a yield advantage of 148 kg/ha with the application of 20 kg S/ha over control (Ali *et al.*, 1993). Aulakh and Pasricha (1986) observed an increase of 27% in lentil yield under Ludhiana conditions with the application of 40 kg S/ha through gypsum on a soil containing 8 kg available sulphur/ha (Table 9.21).

**Micronutrients:** The problem of micronutrient deficiency is likely to be faced in lentil growing areas particularly after rice and similar edaphic situations. The most critical micronutrient being zinc specially on rice soils and most of the studies conducted showed yield improvement with an application of 10-15 kg  $ZnSO_4$ /ha or foliar application with 0.5%  $ZnSO_4$  spray (Sakal *et al.*, 1998). The response to zinc application was found differential in different



genotypes of lentil. Nutrient interaction may also cause zinc deficiency in lentil (Shukursha, 1977). Positive response to boron and molybdenum application in lentil has also been observed at a few locations under AICPIP.

### Fieldpea

The favourable response to fertilizer application has been observed in fieldpea. The optimum dose of N was found 20-40 kg/ha at many locations under AICPIP (Behl *et al.*, 1987). The fieldpea response to applied phosphorus varies depending on the P availability and moisture status of soil (Yadav *et al.*, 1992). In most of the studies, the response was observed from 50 kg  $P_2O_5$  to 100 kg/ha (Yadav *et al.*, 1992; Srivastava and Ahlawat, 1995; Rathi *et al.*, 1995). The response to K application in general, is meagre, although an increase in yield to the tune of 25% has also been observed with the application of 20 kg  $K_2O$ /ha (Ali, 1985). In frontline demonstrations conducted at 16 locations during 2002-07, application of 40 kg/ha sulphur gave 19.7% higher yield over the control (Ali and Kumar, 2009). Amongst micronutrients, significant response to molybdenum application has been observed (Srivastava and Ahlawat, 1995). Application of 0.5 kg/ha molybdenum increased the yield by 80 kg/ha.

### Frenchbean

Unlike other *rabi* pulses, Frenchbean is very inefficient in biological nitrogen fixation due to poor nodulation and therefore requires relatively higher doses of fertilizer N. Application of 90-120 kg N/ha has been found optimum (Ali and Lal, 1991; Nandan and Prasad, 1998; Saxena and Verma, 1995). Multi-location studies conducted under AICPIP revealed an yield advantage of 10.1 and 10.5 q/ha with the application of 120 kg N/ha over unfertilized control in NWPZ and NEPZ respectively (Table 9.23).

Frenchbean responds well to phosphorus application like cereals. Its P requirement is distinctly higher than other pulse crops. Significant response to

**Table 9.23** Effect of N and P on productivity of Frenchbean

Treatments	Grain yield (kg/ha)	
	NWPZ (5)	Central Zone (5)
<i>N levels (kg/ha)</i>		
0	776	534
30	1,173	895
60	1,422	1,216
90	1,626	1,444
120	1,784	1,583
<i>Phosphorus (kg <math>P_2O_5</math>/ha)</i>		
0	1,236	896
30	1,403	1,151
60	1,517	1,360

Figures in parentheses are number of locations

Source: Ali and Lal (1991)



P application has been obtained up to a level of 60 kg  $P_2O_5$ /ha under Kanpur conditions (Saxena and Verma, 1995). On the basis of mean of 5 locations each of NWPZ and Central zone, the response to 60 kg  $P_2O_5$ /ha was found of the order of 281 and 464 kg/ha, respectively, over no phosphorus application (Ali and Lal, 1991). The response to K and micronutrients is meagre.

### Lathyrus

Very few studies have been conducted so far on fertilizer management in lathyrus. Studies conducted under AICPIP obviously revealed the definite response of fertilizer application in improving the seed yield of lathyrus. Application of 10 kg N and 40 kg  $P_2O_5$ /ha increased the yield by 14% over no fertilizer under Dholi (Bihar) conditions. In another study, foliar application of 2% urea at flowering stage resulted in considerable yield increase (35%).

### WATER MANAGEMENT

Water management assumes great importance for successful cultivation of *rabi* pulses as almost all excepting Frenchbean are generally grown on residual moisture and face acute moisture stress during their terminal growth phase. Therefore, efforts should be made to conserve late monsoon rains through appropriate water-conservation measures like contour bunding, deep ploughing /chiselling (if hard pan exists), mulching and water harvesting ponds/reservoirs. In general, a pre-sowing or come-up irrigation helps in ensuring optimum plant population and growth when profile moisture at planting is inadequate. On deep Vertisols, if soil profile is fully recharged at planting time, post-plant irrigation may not be required. However, on light-textured soils, 1-2 irrigations at branching and/or pod development prove highly productive in most winter pulse crops, if winter rains fail. It is advisable to avoid irrigation during active flowering period, otherwise flower shedding and reversion to vegetative growth may occur. Excess water enhances vegetative growth and depresses the grain yield, therefore, only light irrigation (40-50 mm) should be given.

Various approaches for scheduling irrigation, viz. crop growth stage, days interval, cumulative pan evaporation etc., have been adopted. The pod initiation has been found to be the most critical stage in most of *rabi* pulses. Irrigation at other stages is, however, determined by the initial profile moisture, soil type and the climatic conditions under which the crop is grown. Moisture stress at early stage drastically cuts the biological nitrogen fixation which is ultimately reflected into poor yield. Kasturi (1995) recorded marked decrease in nitrogenase activity and nodulation in fieldpea due to moisture stress at early vegetative growth stage under New Delhi conditions on sandy-loam soils.

### Chickpea

Chickpea is capable of drawing water from depths greater than 150 cm (Singh and Bhushan, 1979) but a major proportion of total extractable water comes from the top 60 cm of the soil profile which has the main concentration of active roots (Keatinge and Cooper, 1983). Water availability from a discrete



soil layer, in a rainfed crop, is entirely dependent on the proliferation of roots at that depth, and can be better expressed as 'extractable moisture', i.e. the difference between the maximum moisture content observed in a discrete depth interval and that at maturity (Ritchie, 1981). Multi-location studies under AICPIP on water management in chickpea revealed that two irrigations, one each at branching and pod formation, increased grain yield by 25-32% in central India (Table 9.24). In areas of

high moisture stress, irrigation may considerably improve the productivity. In NWPZ and NEPZ, response to irrigation is generally low due to winter rains and high relative humidity. Early irrigation may induce excessive vegetative growth as well as poor aeration in heavy-textured soils and therefore should be avoided.

As regards irrigation scheduling on the basis of climatological parameters, irrigation at 0.4 IW : CPE ratio proved most productive at Kharagpur. The yield grain with irrigation at IW : CPE 0.4 was 67% as compared to that at IW : CPE 0.8. At Kanpur, two irrigations, one each at branching and pod initiation, resulted in the highest grain yield. Similarly at Hisar, the crop responded well to two irrigations with increased water-use efficiency (Table 9.25).

### Fieldpea

Fieldpea needs relatively better moisture regime than chickpea. In North-East Plains (Faizabad), one irrigation at flower-initiation stage (50 DAS) was found most promising (Yadav *et al.*, 1992) whereas in Central India (Jabalpur), two irrigations, one each at branching and flowering, were found optimum (Rathi *et al.*, 1995). In NWPZ (Navgaon, Rajasthan) too, branching and flowering stages were found most critical (Table 9.26). Of two types, dwarf genotypes like Aparna responded better to irrigation than tall types as they do not lodge.

**Table 9.24** Response of chickpea to irrigation in central India

Irrigation schedule	Grain yield (kg/ha)	
	Navsari	Dohad
No irrigation	1,378	2,107
Irrigation at branching	1,462	2,296
Irrigation at pod formation	1,410	2,510
Irrigation at branching + pod formation	1,724	2,786

Source: Singh and Ali (2003)

**Table 9.25** Effect of irrigation and sulphur on seed yield and water-use efficiency (WUE) of chickpea

Treatment	Seed yield (kg/ha)	WUE (kg/ha-mm)
<i>Irrigation</i>		
Control	1,427	7.75
One	1,547	7.30
Two	1,661	7.01
CD (P = 0.05)	80	
<i>Sulphur (kg/ha)</i>		
Control	1,426	6.93
20	1,558	7.33
40	1,651	7.68
CD (P = 0.05)	80	

Source: Singh *et al.* (2004).

**Table 9.26** Response of chickpea and fieldpea to irrigation in Central zone

	Grain yield (kg/ha)			
	Chickpea		Fieldpea	
	Navsari	Dohad	Navgaon	Jabalpur
No irrigation	1,378	2,107	1,344	850
Irrigation at branching	1,462	2,296	1,756	1,660
Irrigation at pod formation	1,410	2,502	1,874	1,420
Two irrigations, branching and pod formation	1,724	2,786	2,103	1,770

Source: AICPIP (1989)

### Frenchbean

Frenchbean is the most irrigation responsive pulse crop due to its shallow root system and high nutrient requirements. Multi-location studies under AICPIP showed that Frenchbean needs 2-3 irrigations in NEPZ, and 3-4 irrigations in Central Zone for achieving highest productivity (Ali and Lal, 1991). Irrigation at 25-day crop stage was the most critical. As regards irrigation schedule on climatological basis, 0.6 to 0.8 IW : CPE ratio is optimal (Shiv Dhar and Singh, 1995).

### Lentil

The most critical growth stage for moisture stress in lentil is pod formation followed by the initiation of flowering. In case of failure of winter rains, one to two irrigations are required for higher productivity of the crop. The effect of irrigation is more prominent in late planted crop due to poor root development. Venkaterwarlu and Ahlawat (1993) observed significant yield increase owing to irrigation, higher yield was obtained under wet moisture regime (0.6 IW : CPE) as compared to dry moisture regime (0.35 IW : CPE) under Delhi conditions on sandy-loam soils.

### Lathyrus

Lathyrus is generally grown under relay cropping with rice under rainfed conditions. However, under high moisture-stress conditions, one irrigation at 60-70 days crop stage has proved highly productive in Chhattishgarh region.

## WEED MANAGEMENT

Weeds compete with crop plants for various production resources such as nutrients, moisture, sunlight and space, and consequently reduce yield. Pulses being poor competitor to weeds specially during initial growth stages suffer considerable yield loss. The degree of yield loss varies from 18 to 90%, depending on the growing conditions, crop species and management practices.

Winter pulses are infested with annual and perennial grasses, broad-leaf weeds and sedges. The important weeds associated are: *Phalaris minor*, *Avena ludoviciana*, *Lolium temulentum*, *Trifolium* spp., *Chenopodium album*, *Melilotus* spp., *Lathyrus aphaca*, *Convolvulus arvensis*, *Anagallis arvensis*, *Asphodelus*



*tenuifolius*, *Medicago denticulata*, *Rumex dentatus*, *Fumaria parviflora*, *Cirsium arvense*, *Cyperus rotundus*, *Cynodon dactylon*.

In order to develop an efficient, cost-effective and environmentally safe weed management schedule, it is imperative to determine the critical period of crop-weed competition and need of crops to have weed-free environment for better growth and development. This provides information on the crop growth phase which is more vulnerable to weeds competition. Emergence of weeds and crops are generally simultaneous in the field. But weeds on account of their better adaptation and survival mechanism even under adverse conditions and fast growing habit supercede the crop plants. The degree of loss depends on the nature and magnitude of weed infestation. This period varies in different pulse crops. In chickpea and lentil, initial 30-60 days are most critical whereas in fieldpea and *rajmash* it is initial 40-60 days.

Various methods of weed management such as cultural, mechanical, chemical etc. have been practiced with different degree of success in different agro-ecological zones and production systems.

**Cultural:** Cultural practices are manipulated in such a way that they become more favourable for crop growth and less favourable to weeds. It may include change in rotation, adopting suitable cropping systems, selection of suitable genotypes, date of sowing and plant population adjustment. They are not only eco-friendly but also reduce use of costly herbicides. The choice of appropriate genotypes, date of planting, plant geometry and cropping systems are some of the major components of the cultural practices which influence weed infestation in crop field. Planting time considerably influences the occurrence and manifestation of weed species. In timely sown chickpea, the weed population by 30 days is generally quite high to attract manual weeding whereas in late sown chickpea the build up of adequate weed flora is only after 45 days. Delayed sowing of lentil and chickpea is also reported to reduce the infestation of *Orobancha* root parasite (Linke and Saxena, 1989).

**Mechanical:** Mechanical weed control involves removal of weeds by hand pulling or with various tools and implements. Inter-cultural operations are performed primarily to destroy the weeds present in the field and create favourable soil conditions for growth of pulses. Hand-hoeing and manual weedings are the most common practices performed for weed control in almost all pulse crops. One or two hand-weedings at critical crop-weed stage provide satisfactory control of weeds in most of the *rabi* pulse crops (Ali, 1997).

**Chemical:** Herbicides being selective, dependable and effective against target weeds gained popularity in the recent years specially under intensive agriculture. In India use of herbicides for weed management is meagre compared to developed nations. This is mainly due to low purchasing and risk-bearing capacity as well as poor perception of dry-land tenants about weed management. Nevertheless, experimental evidences and on-farm demonstrations have shown that use of herbicides such as alachlor, pendimethalin and fluchloralin is highly effective against seasonal weed flora. Pre-plant incorporation of fluchloralin 0.75 kg/ha has been found very effective against most of the annual grasses and non-grassy weeds in lentil. Results of multi-



location studies under AICPIP during 1983-85 showed that fluchloralin 1.0 kg/ha, pendimethalin 0.75 kg/ha and oxidiazon 0.75 kg/ha were quite effective in controlling weeds in pulses. Pre-emergence application of pendimethalin 1.0 kg/ha or pre-plant incorporation of fluchloralin 0.5 kg/ha is quite effective in controlling weeds in chickpea, Frenchbean, pea and lentil. Pre-plant incorporation of fluchloralin @ 1.5 kg/ha resulted in higher yield and net returns from chickpea + mustard intercropping system (Singh and Singh, 1998). It significantly reduced the weed density and biomass over unweeded control. Pre-plant incorporation of herbicide (fluchloralin) is an additional operation and incurs extra cost and therefore preference is for pre- or post-emergence herbicides.

**Soil solarization:** Soil acts as a reservoir of weeds seed and therefore, the importance of soil solarization in destroying the weed seed reserve is well recognized. By covering of soil with polythene sheet, the soil temperature is increased to the lethal level for weeds. Soil temperature increases to the tune of 8-12°C by soil solarization over corresponding non-mulched soil. Katan (1981) reported that most of the annual and perennial weeds belonging to genera *Amaranthus*, *Anagallis*, *Avena*, *Chenopodium*, *Convolvulus*, *Digitaria*, *Eleusine*, *Fumaria*, *Lactuca*, *Phalaris*, *Poa*, *Portuloca*, *Solanum* and *Xanthium* were effectively controlled by soil solarization. Variability in weed control due to soil solarization is influenced by soil type, temperature, moisture content, size and depth of seeds or vegetative propagules in soil, besides the polythene film quality.

**Integrated weed management:** Integrated weed management system (IWMS) is basically integration of effective, dependable and workable weed-management practices such as cultural, mechanical, chemical and biological that can be used economically by the producers as a part of a sound farm-management system. This approach entirely takes into account the need to increase agricultural production, reduces economical losses, risk to human health and potential damage to flora and fauna that we do not want to affect adversely, besides improving the safety and quality of environment. Mishra and Bhan (1997) obtained higher grain yield owing to better weed control with application of fluchloralin or pendimethalin @ 1.0 kg/ha + one weeding at 30 DAS in pea at Jabalpur. The lower dose of pendimethalin (0.75 kg/ha) + one weeding 45 DAS was effective in controlling weeds in lentil crop at Kanpur (Ali and Nath, 1998). In rice-lentil sequence under dryland conditions of Varanasi, weeds were effectively controlled in lentil crop with the application of paraquat+no preparatory tillage + prometryne as pre-emergence.

## PLANT PROTECTION

### Chickpea

**Insect-pests:** About two dozen species of insects and other arthropod pests are known to attack chickpea in India. Amongst them, pod-borer, cutworms, semiloopers, termite and aphids are of economic importance.

**Gram pod-borer:** Gram pod borer (*Helicoverpa armigera*), distributed throughout the country, is the key pest of chickpea. It may cause heavy damage (20-60%) especially in humid-hot environments, and late-sown conditions. The



young larvae feed for a short period on tender organs of the plant. With the pod formation, larvae feed on developing seeds after cutting a round hole in the pod and pushing its head inside the pod. Normally, the larvae remain hidden in the foliage of the crop unnoticed till the formation of pod.

*Gram semilooper:* Gram semilooper (*Autographa nigrisigna*) is a widely distributed but a minor pest. In north India, the incidence is relatively high. The pest is commonly known as a semilooper, because the caterpillar forms a loop at the centre of the body when it moves. The larvae feed on the leaves, buds and flowers in the beginning and later on tender pods too. It devours the whole pod including the seeds leaving only a small part of pod attached to pedicel.

*Termites:* Termites (*Odontotermes obesus* and *Microtermes obesi*) are subterranean pests and more prevalent in relatively dry tracts, especially in sandy and sandy loam-soils. Termites appear soon after sowing and damage the emerging seedlings. The attacked plants in younger stage wither away and die forthwith, whereas the grown-up plants die slowly. Such plants, if uprooted, will show the presence of termites and their galleries on damaged plants.

*Cutworm:* The pest, cutworm (*Agrotis ipsilon*) is common throughout the country but serious in northern India, particularly in flood-affected areas and soils rich in organic matter. The insect remains hidden during day and becomes active during night. The caterpillar cuts the plants at the base, below or just above the soil surface or may even cut branches. A characteristic feature of the damage is that the caterpillars drag the cut parts into soil for feeding.

*Aphid:* The infestation by aphid (*Aphis craccivora*) is sporadic and localized. It occurs throughout the country but is more serious in western Uttar Pradesh, Haryana and Punjab, specially on late-sown crops. The nymphs and adults infest the tender shoots and pods and suck the sap which may result in drying up of the tender shoots. In late stages, the tender pod may shrivel and dry and/or the seeds remain poorly developed.

#### *Control measures of insect-pests*

Soil or seed treatments should be practiced as a preventive measure against termites and cutworms in the fields having a previous history of occurrence of these pests. The specific recommendations against major insect-pests are discussed here.

*Gram pod-borer and semilooper:* A number of cultural and chemical means are available; however, an integrated approach involving all possible means available for the management of pod-borer provides better, effective and ecofriendly management. The cultural practices involve ploughing up the field after harvesting of the crop to expose hibernating pupae of not only *Helicoverpa* but other insects like cutworm also, clean cultivation, removing plant debris, early planting, intercropping with mustard, linseed, safflower etc. Care must be taken to conserve natural enemies. Installation of bird perches @ 50/ha encourages sitting of predatory birds that prey on the caterpillars.

Critical monitoring of moth population through pheromone trap is imperative to forewarn the epidemic of pest and decide the time of pesticide



use. Use of insecticide should begin only when the pod-borer reaches threshold level, i.e. 1-2 larvae/linear m row or 3-4 moths trapped/night in 4-5 successive nights. Dusting the crop with malathion 5% or carbaryl 5% or phosalone 4% at the rate of 20 to 25 kg/ha in the early hours when the crop is wet with sufficient dew or spraying of the crop with insecticides such as chlorpyrifos 2 ml/litre or with botanical pesticides like neem-seed-kernel extract 5%, Nimbecidin, Neemex, Achook or other neem-based products or microbial products like NPV 250 LE/ha, *Bacillus thuringiensis* (Delfin) 1 kg/ha provides effective control against gram pod borer. Some newer insecticides like indoxacarb @ 1 ml/litre, or spinosad 0.4 ml/litre or emamectin benzoate 0.4 ml/litre are also effective in management of pod-borer.

Synthetic and botanical/microbial insecticides should be sprayed alternatively to reduce the dose of chemical and avoid development of insecticide resistance in the pests. Control measures directed at pod-borer also effectively manage semilooper.

**Termite:** If attack appears after sowing, drench the soil through spraying with lindane @ 0.03% EC in 1,500 to 2,000 litres of water. Chlorpyrifos is also effective against termites.

**Aphids:** Aphids are very delicate insects and can be managed by use of any insecticide like acephate, malathion, demeton, dimethoate, thiometon, phosdrin, and synthetic pyrethroids, viz. fenvalerate and cypermethrin.

### Diseases

Chickpea is affected by several fungal, bacterial and viral diseases. Some of the important diseases causing substantial loss in chickpea production in different agro-ecological zones of India are discussed here.

**Wilt:** It is a soil-borne fungal disease caused by *Fusarium oxysporum* f. sp. *ciceri*. It is prevalent throughout the country but is most serious in central zone. The disease generally appears 3 weeks after sowing. Internal tissues from the collar region downwards become dark and discoloured. The petioles and rachis along with leaflets droop down. Drooping starts from the upper part of the plant but soon the entire plant droops down. Sometimes only partial wilting of plants may occur.

Wilt disease is like a cancer; once a plant is infected it is difficult to cure it. It is therefore advised that the measures for its management need to be taken well in advance. Several genotypes resistant to *Fusarium* wilt have been released for cultivation (Table 9.3) which should be popularized in wilt infested areas. Deep summer ploughing, appropriate crop rotation, balanced use of fertilizers including K, roguing out the infected plants from the field, and treating the seeds before sowing with thiram or captan or bavistin @ 250 g/q seed minimizes disease infestation. Alternatively, seeds may also be treated with bioagents like *Trichoderma* @ 6 g + 1 g vitavax/kg.

**Collar rot:** It is a soil-borne fungal disease caused by *Sclerotium rolfsii*. The disease mostly appears in the seedling stage under high soil-moisture conditions. Young seedlings collapse, which in older seedlings the leaves turn yellow and the plants dry up. Rotting of the stem can be seen at the collar



region, the rotten portion of the stem is covered with whitish mycelial growth of the fungus and the disease may appear in patches in the field.

Treating the seed before sowing with rhizoctol or captan or thiram fungicides @ 0.2% (w/w) or Bayton 10 DS or vitavax 200 at 0.25% (w/w) effectively reduces the disease. Drenching the soil with demosan (15 kg/ha) helps check disease development. Timely sown crop with optimum soil moisture gets relatively less disease than the early sown crop with excessive soil moisture.

**Wet root rot:** It is a soil-borne fungal disease caused by *Rhizoctonia solani*. The disease generally occurs at seedling stage under high soil moisture. Affected seedlings gradually turn yellow with drooping of petioles and leaflets. Generally, the seedlings do not collapse. In the infected seedlings a distinct dark brown lesion appears above the collar region on the main stem. Roots of the affected plants are damaged due to rot.

Improving the drainage, roguing infected plants, growing resistant varieties, treating the seed before sowing with captan or thiram @ 2-3 g/kg seed or soil application of thiram before sowing @ 25 kg/ha are recommended for management of wet root rot.

**Black root rot:** It is caused by *Fusarium solani*, a soil-borne fungus. The disease can occur at any stage of growth but is favoured by excessive soil moisture coupled with moderate temperatures and is more common in irrigated crops. Affected seedlings gradually turn yellow and the foliage droop. The root system is rotten and the thick roots along with the main root turn black. Affected plants dry prematurely and can be seen scattered in the field. Affected plants often continue producing new roots if there is sufficient soil moisture.

Improving the drainage, roguing infected plants, growing resistant varieties, treating the seed before sowing with captan or thiram 0.2% by weight and soil application of thiram before sowing @ 25 kg/ha are recommended for management of black root rot.

**Dry root rot:** It is a soil-borne fungal disease caused by *Rhizoctonia bataticola*. The disease generally appears around flowering and podding. Maximum atmospheric temperature above 30°C, minimum above 20°C and moisture stress at flowering/podding stage favour disease development. Disease appears in scattered patches in the field, the petioles and leaflets of the infected plant droop only at the very top and finally the infected plants dry up. When the infected plants are pulled out, the tap root usually remains in soil, it turns dark showing signs of rotting.

Growing resistant varieties, appropriate crop rotation, treating the seed with thiram 0.25% and soil application of thiram before sowing @ 25 kg/ha minimizes disease infestation.

**Stem rot:** It is soil-borne fungal disease caused by *Sclerotinia sclerotiorum*. The disease appears on adult plants especially in the crop having thick canopy and excess soil moisture. The petioles and leaflets droop, the leaves dry up and turn straw coloured prematurely, a web of white mycelial strands appear in the affected plant parts.

Excessive moisture and dense canopy which are conducive for stem rot



should be avoided. Clean cultivation also helps in minimizing disease incidence. Foliar spray of fungicide like bavistin @ 1 ml/litre is effective in checking the disease development.

**Ascochyta blight:** It is a fungal disease caused by *Ascochyta rabiei*. Seed-borne infection provides inoculum for the initiation of primary infection. Secondary spread is through conidia or ascospores. It is most potential disease of North-West Plains. Small circular brown spots appear on the leaves. These spots have discoloured margin. Later black minute dots appear on necrotic lesions arranged in circles. Cool, cloudy and wet weather favours development of this disease.

Use of tolerant varieties like Gaurav (H 82-2), GNG 469, GNG 1581, PBG 1, GNG 663 etc., roguing out the infected plants, seed treatment with thiram or benomyl @ 2 g/kg or Calixin-M or thiabendazole @ 3 g/kg reduces seed-borne infection (Nene *et al.*, 1991). Seed treatment with hexacap or captan or captaf or combinations of bavistin+thiram (1:1) @ 3 g/kg or rovril @ 2.5 g/kg can also help control the disease (Singh and Singh, 1990). Foliar sprays with captan or dithane M 45 or hexacap or captaf or kavach @ 3 g/litre provide effective control of the disease.

**Botrytis grey mould:** It is caused by the fungus *Botrytis cinerea*. It is most common in tarai region. Cool weather with high humidity favours occurrence of the disease. The disease appears on all parts of the plants except root system. Grey or dark brown lesions are seen on infected parts. Excessive vegetative growth is conducive for this disease. At present genotypes resistant to Botrytis grey mould (BGM) are not available, therefore cultural practices such as wider spacing, intercropping, late planting etc. should be followed. Seed treatment with fungicides like thiram + bavistin (1:1), dithane M 45, bavistin @ 3 g/kg or thiabendazole @ 2 g/kg or rovril or ronlan @ 4 g/kg is effective in eliminating seed-borne infection (Grewal and Laha, 1983; Singh and Kaur, 1990). Disease can be effectively managed by spray the crop with Dithane M 45 @ 3 g/litre or thiabendazole or bayleton or bayton @ 2 g/litre (Haware *et al.*, 1997).

**Stunt:** It is a viral disease mostly prevalent in Gujarat State. Plants are stunted with short internodes, smaller yellow, orange or brown leaflets. The phloem tissues also turns brown. Resistant varieties are not available. Varieties Girnar, JG 16, Pusa 244, Udai are however tolerant to stunt disease and may be used in areas where stunt is a problem. Control of leaf hoppers and aphids, the vectors of the viruses known to cause stunt disease and late sowing are recommended for management of stunt.

### Fieldpea

**Insect-pests:** Insect-pests causing damage to pea crop are stemfly (*Ophiomyia phaseoli*), leaf miner (*Phytomyza atricornis*), aphid (*Aphis craccivora* and *Acyrtosiphon pisum*) and spiny pod-borer (*Etiella zinckenelia*). These pests are widely distributed in the country. However, intensity of attack and extent of damage in different agro-climatic zones vary across locality and season.



*Pea stemfly:* It is widely distributed major pest. Eggs are laid in the cavities made by it on leaves, petiole or the tender stem. Maggots (after emergence) mine the leaf petiole or tender stem and feed within. Young plant droops down, leaves turn pale-yellow and ultimately it dies. Damage to grown-up plants results in stunted growth and sickly appearance.

*Leaf miner:* It is widely distributed in north India. Adult females deposit the eggs by puncturing the leaf. Young maggot mines the leaf and feeds within. Infested leaves show numerous zigzag mines or galleries. Normally, it is a minor pest but may become serious.

*Aphids:* Normally, aphids are considered as a minor pest of pea, but sometimes they cause severe damage to the crop. Both nymphs and adults feed on plant sap resulting in the depletion of assimilates. Severe infestation results in deformed, withered and malformed leaves, shoots and pods. Infested plants are often stunted followed by honeydew deposition on which develops black sooty molds; and infested plants finally dry up. Aphids also act as vector of many viruses known to infect pea.

*Spiny pod-borer:* This pest is more common in north India. Late-maturing types are more prone to its damage in comparison to early types. Similarly, late-sown crop is subjected to more damage as compared to early-sown crop. Eggs are laid by the moth at the junction of calyx and pod or on pod surface. The young larvae after hatching bore into the pods and feed inside on developing seeds.

#### *Control measures of insect-pests*

- (a) For stemfly, leaf miner and aphids, seed treatment with 2% carbofuran (4%) or soil application of phorate 10 G @ 1 kg a.i./ha at the time sowing is quite effective. If necessary, this may be followed by spraying monocrotophos 0.04%, or malathion 0.05% or dichlorvos 0.05% or dimethoate 0.03% in 400 to 500 litres water/ha at podding stage.
- (b) If soil treatment at the time of sowing has not been done and control measures are required, spraying with malathion 0.05% or monocrotophos 0.04% or dichlorvos 0.05% or dimethoate 0.03% or metasystox 0.05% may be done depending on pest incidence.
- (c) For pea pod-borer, crop may be sprayed with monocrotophos 0.04% at 10 to 15 days interval beginning with pod formation.

#### *Diseases*

*Powdery mildew:* It is a fungal disease caused by *Erysiphe polygoni*. White powdery growth of fungus mycelium and spores develop on leaves, branches, stems, tendrils, petioles and pods. In case of severe infection, pods get loose and look dull; the seeds may develop a grey-brown discolouration.

Several powdery mildew-resistant varieties such as Rachna, Pant Matar 5, DMR 27, HUP 2 are available. In case of occurrence on susceptible varieties, spray wettable sulphur 70 WP (Sulfex) 0.3% or bavistin 0.1% or dinocap or karathane 48 EC @ 0.05 ml/litre. If needed, spray can be repeated at 10 days interval.



**Rust:** It is caused by a fungus, *Uromyces fabae*. Light to bright-yellow (turmeric powder) colour rust pustules are found on all above-ground plant parts, more on lower surface of leaves. Pustules gradually become reddish-brown. Severely infected leaves shrivel and fall off. Stem infection results in cracking and breaking of stem which leads to drying and death of plant.

Use of tolerant varieties recommended for the area and early/timely sowing help avoid losses caused by rust disease. Heavy irrigation at the later stages of the crop should be avoided. In case of rust occurrence, use fungicides like wettable sulphur 70 WP (Sulfex) 0.3% or Dithane M 45 @ 0.2 % as foliar spray. Number of spray depends on the severity of the disease.

**Pea stem rot:** It is a fungal disease caused by *Sclerotinia sclerotiorum*. As a result of infection, white cottony growth of a mycelium appears on the stem and pods. Affected tissues become siliny. Disease is often seen in the low-lying areas of field. Affected stems appears bleached and generally large. Infection at collar region results in the wilting of affected plants. Seed treatments and foliar spray with fungicides like bavistin and difolaton @ 0.2% are helpful in checking development of the disease.

**Damping-off:** It is a fungal disease caused by *Pythium* sp., *Rhizoctonia solani* and *Fusarium* sp. Young germinating seedlings are attacked at ground level, stem becomes brown and constricted and finally collapse resulting in poor stand of the crop. Seed treatment with thiram or bavistin @ 2-3 g/kg minimizes disease infestation.

**Downy mildew:** It is a fungal disease caused by *Peronospora pisi*. Yellowish spots on upper surface of leaves corresponding to white, cottony fungal growth of conidiophores and conidia on lower surface. Affected plants are stunted and leaves drop prematurely. Deep sowing should be avoided. Seed treatment with systemic fungicides help reducing the incidence of disease.

## Lentil

### Insect-pests

Lentil is attacked by several insect-pests, however, aphid (*Aphis craccivora*) and spiny pod-borer (*Etiella zinckenella*) are important throughout country. *Aphis craccivora* is the dominant among the other aphid species which attack and damage lentil crop. In case of severe infestation, leaves and shoots get deformed and stunted and sticky honey dew may be deposited over the leaf surface. Spiny pea pod-borer *E. zinckenella* causes minor to moderate damage except in certain years when it has been reported to cause serious damage to lentil pods. Freshly hatched larvae construct a web-type structure through which they enter the pods. After 2-3 days feeding inside the seed, the larva comes out to feed superficially on the seeds. In the secondary infestation, the caterpillar feeds by webbing 2-3 healthy pods.

In nature predators are usually very active against aphids. Caution should be taken not to harm the natural predatory population while spraying insecticides. Safer insecticides should be selected; systemic ones should be preferred over others. A large number of insecticides have been recommended. Important among them are cypermethrin 0.004%, demeton methyl 0.05%,



dimethoate 0.03%, fenvalerate 0.01%, malathion 0.05%, etc. Usually only one spray is required to control aphid damage.

### Diseases

The major diseases of lentil are wilt (*Fusarium oxysporum* f. sp. *lentis*) and rust (*Uromyces fabae*). However, occasional incidence of stem rot (*Sclerotinia sclerotiorum*), collar rot (*Sclerotium rolfsii*), root rot (*Rhizoctonia* spp.), powdery mildew (*Erysiphe polygoni*), ascochyta blight (*Ascochyta lentis*) and alternaria blight (*Alternaria alternata*) are also observed specially under humid conditions.

**Wilt:** Wilt is caused by the fungus *Fusarium oxysporum* f. sp. *lentis* that is host specific. Disease may occur at any stage of the crop. However, mortality mainly occurs at seedling and flowering/podding stages. Several wilt-tolerant varieties have been released and may be used as per the recommendation for an area. Some of the wilt-tolerant varieties are: Pant L 406, Pant L 234, Pant L 639, Sapna, VL Masoor 4, Pant Lentil 4, Lens 4076, Pusa Vaibhav, Narendra Masoor 1, DPL 62, Subrata, Jawahar Lentil 3, VL Masoor 507, Pant Lentil 6, Pant Lentil 7. Appropriate crop rotation, roguing out the infected plants from the field, and treating the seeds before sowing with thiram or thiram + carbendazim (1:1) @ 2.5 g/kg seed minimizes disease infestation.

**Rust:** It is caused by the fungus, *Uromyces fabae*. Symptoms start as yellowish pustules on the leaflets and pods. Later, light-brown pustules appear on both the surfaces of the leaves and other aerial parts of the plant. The pustules finally become dark brown. Severe infection leads to the defoliation and drying up of the infected plants. Use of resistant/tolerant varieties like Pant L 4, L 4076, Pant L 5, Pusa Vaibhav, Narendra Masoor 1, DPL 62, Haryana Masar 1, HUL 57, IPL 406, WBL 77, Pant Lentil 6, Pant Lentil 7 as per the recommendations for the area should be practiced.

Foliar spray with wettable sulphur @ 0.3% or diathane M-45 @ 0.02% provides satisfactory control of rust disease. Diathane M-45 is recommended against *Alternaria* blight and *Ascochyta* blight also. Spray should start at the first notice of disease and may be repeated depending on the severity of the disease.

### Rajmash (Frenchbean)

**Insect-pests:** Sucking insects like aphids, whitefly, jassids and lepidopteran pests are the major pests of *rajmash*. Foliar spray of insecticides such as acephate, malathion, methyl demeton, dimethoate and synthetic pyrethroids, viz. fenvalerate and cypermethrin, are recommended for the management of sucking pests and lepidopteran pests.

**Diseases:** Root rots, stem blight, anthracnose, leaf spots and Bean common mosaic are major diseases of *rajmash*. Root rots caused by *R. solani* and *Fusarium* spp. can be managed by treating seeds with thiram or bavistin @ 2-3 g/kg. Foliar spray of bavistin @ 0.2% is recommended against stem blight (*S. sclerotiorum*), anthracnose (*Colletotrichum lindemuthianum*) and other fungal leaf-spot diseases. Use of resistant varieties is the best option for avoiding losses caused by bean common mosaic virus. *Rajmash* varieties like Amber, Utkarsh etc. are tolerant to bean common mosaic. Incidence of bean common mosaic virus can be reduced by using certified disease-free seeds and by controlling the aphid vectors.



### CROPPING SYSTEMS

*Rabi* pulses are grown under different cropping systems such as monocropping, double cropping, relay cropping and mixed cropping. The choice of a particular system depends on irrigation potential, annual rainfall and its distribution, edaphic conditions, domestic needs and trade opportunity.

#### Monocropping

Monocropping (100% cropping intensity) is generally practised in rainfed areas of Central and Peninsular zones where monsoon rains are insufficient to allow double cropping and also the soils are too clayey to work during the rainy season. Under such a system chickpea/lentil is rotated with *rabi* sorghum or durum wheat in a 2-year crop rotation. The soils of these areas are generally heavy-textured and therefore, the soil profile once recharged during the monsoon season, supports a successful crop of chickpea and lentil. Monocropping is also prevalent in flood-affected and *tal* areas (*diara* land) of eastern Uttar Pradesh, Bihar, West Bengal and Odisha where chickpea, lentil and pea are planted after receding floods. The soils of *tal* areas are quite fertile because of silt deposits and thus produce a bumper crop.

#### Double cropping

In areas having assured rainfall (eastern, Bihar, West Bengal) or irrigation potential (Punjab, Haryana, Western Uttar Pradesh), *rabi* pulses are grown under double cropping (200% cropping intensity) to sustain the productivity of soil, break disease cycle and optimize production resources. Winter pulses like chickpea, lentil and peas are grown after *kharif* maize, sorghum, pearl millet, short-duration cotton and early rice. In the recent years, there has been an increasing awareness about cereal-legume rotation and consequently new crop rotations are spreading in different regions. Rice-chickpea/lentil and maize-Frenchbean/pea in NEPZ, cotton-chickpea in NWPZ and soybean-chickpea in CZ (Madhya Pradesh) are gaining ground. It is well recognized that winter pulses like chickpea, lentil and peas improve physical, chemical and biological properties of soil and economize N by 30-40 kg/ha in the succeeding cereal (Table 9.27). Field studies at the IARI, New Delhi, during 1975-77 showed that plots seeded to winter grain legumes maintained a higher level of soil fertility (total N and available P) at the time of harvest than those under wheat

**Table 9.27** Energy saving through nitrogen economy by different legumes

Preceding legumes	Succeeding cereal	N economy (kg/ha)	Energy saving (10 <sup>9</sup> joules/ha)
Chickpea	Maize	56-68	45-54
Chickpea	Pearlmillet	40	32
Lentil	Maize	18-30	14-24
Lentil	Pearlmillet	40	32
Peas	Maize	20-32	16-25
Peas	Pearlmillet	40	32
Lathyrus	Maize	36-48	29-38



(Table 9.28). This could be attributed to biological  $N_2$  fixation and the improvement in physio-chemical and microbial conditions of the soil. Among various legumes, chickpea recorded a higher content of total N and available P followed by pea and lentil. The yield of succeeding maize at zero level of N was 2.25 tonnes/ha after lentil, whereas it was only 1.35 tonnes/ha after wheat and 1.66 tonnes/ha after winter fallow. The N economy accrued because of winter legumes added 18 to 68 kg N/ha in succeeding maize (Ahlawat *et al.*, 1981).

**Table 9.28** Fertility status of the top 30 cm soil profile as influenced by winter legumes after harvesting at New Delhi, 1975-77

Winter crop	Total N (%)	Available P (kg/ha)
Chickpea	0.069	12.2
Lentil	0.064	10.8
Pea	0.065	11.1
Wheat	0.048	9.8
Fallow	0.052	9.6

In another study at Khargone in Madhya Pradesh, Ali (1987) reported that sorghum yield was significantly improved with preceding winter legumes (chickpea, lentil and pea). The grain yield of sorghum at zero N level was 2.27 tonnes/ha after lentil, whereas it was only 1.12 tonnes/ha after wheat. The beneficial effect of winter pulses on succeeding cereals has also been reported by other workers (Meena and Ali 1987; George and Prasad, 1989). Winter pulses are also grown in rotation with sugarcane both in Indo-Gangetic plains and in central and south India.

### Relay cropping

Relay cropping of lentil and lathyrus is very common in eastern India and also in Chhattishgarh. In this system, seeds of lentil/lathyrus are broadcast in standing rice 7-10 days before its harvest. The main objective of relay (*paira*) cropping is to ensure good plant stand of winter pulses and make best use of residual soil moisture of rice fields. Medium-maturity rice cultivars are generally taken under these systems.

Relay planting has been found to be more productive than planting after the harvest of rice, as the former practice enables better and earlier establishment of lentil/lathyrus seedlings because of an adequate availability of soil moisture which otherwise tends to get quickly lost once the rice is harvested. Roysharma *et al.* (1984) at Dholi in Bihar found that *paira* cropping of lentil produced 1.27 tonnes/ha compared with 0.54 tonnes/ha when planting was done after harvest of rice.

### Mixed/intercropping

Traditionally, *rabi* pulses like chickpea, lentil, peas etc., are grown mixed with wheat and barley in Indian sub-continent, west Asia and Euthopian Highlands where subsistence farming predominates (Saxena, 1987). However, with increasing demand of oilseeds and introduction of dwarf genotypes of



wheat/barley in the recent years, the area under wheat/barley + winter pulse intercropping is decreasing progressively. Sharma *et al.* (1987) reported that intercropping of chickpea and lentil with wheat was not a sound proposition.

Intercropping of winter oilseeds such as mustard, linseed and safflower with chickpea and lentil is widely adopted under rainfed conditions. Comprehensive studies under AICPIP during 1982-92 revealed that chickpea + mustard and lentil + mustard in northern plains, chickpea + linseed in central plateau and chickpea + safflower in peninsular zone are the most profitable intercrops. Higher productivity and monetary returns from chickpea + mustard intercropping have been reported by several workers (Mehta *et al.*, 1990; Sachan and Uttam, 1992; Ali 1992).

In the past, intercropping research has mainly focussed on selection of compatible crops for various agrotechnological zones, and relatively little attention has been paid for developing genotypes especially suited to intercropping situations. Experimental evidences have shown that the genotypes which gave higher yield in sole-cropping system are not necessarily high yielders in intercropping systems (Green *et al.*, 1981).

In a study on chickpea + mustard (4:1 row ratio) intercropping on Inceptisols at Kanpur, chickpea genotypes exhibited differential performance under sole and intercropped situations (Ali, 1992). In sole stand, semi-erect *desi* genotype BG 256 gave the highest yield (2.72 tonnes/ha) but in intercropping situation, erect-tall type BG 261 and early maturing genotype PDG 84-16 gave relatively higher yield and enhanced total productivity of the system (Table 9.29). Reduction in chickpea yield under intercrop situation over sole crop was 41.9% in BG 256, whereas in BG 261, it was only 32.5%. Mustard yield was low with BG 256 as compared to BG 261 and PDG 84-16.

The planting pattern and spatial arrangement considerably influence competition among component crops. It is, therefore, imperative to adopt an appropriate plant geometry which minimizes competition and at the same time enhances total productivity. Studies in past have shown that row planting system is far superior to seed mixed-broadcast system, as it ensures better plant stand, equitable distribution and ease in cultural management. At Faizabad (Uttar Pradesh), chickpea-based intercrops evaluated under row planting and seed mixed-broadcast (Singh and Yadav, 1992) indicated that the total productivity (chickpea equivalent) under row planting was 1,878, 2,520 and 1,749 kg/ha as

**Table 9.29** Genotypic compatibility of chickpea intercropped with mustard

Genotypes	Chickpea yield (tonnes/ha)		Mustard yield (tonnes/ha)	Reduction in intercrop over sole crop (%)
	Sole	Intercrop		
BG 256	2.72	1.58	1.07	41.9
BG 261	2.18	1.47	1.40	32.5
BG 267	2.44	1.38	1.40	43.4
PDG 84-16	2.53	1.51	1.38	40.3

Source: Ali (1992)



against 1,384, 1,935 and 1,514 kg/ha for chickpea + barley, chickpea + mustard and chickpea + wheat respectively (Table 9.30). When the component crops are sown in rows, different row ratios are used depending on domestic needs and growth rhythms of the component crops.

**Table 9.30** Effect of planting systems on productivity (kg/ha) of chickpea based intercropping under rainfed conditions

Intercrops	Mixed cropping (seed mixed broadcast)			Intercropping (2:1) (row planting)		
	Chickpea equivalent	Chickpea	Intercrop	Chickpea equivalent	Chickpea	Intercrop
Chickpea + barley	660	1,933	1,384	1,398	1,279	1,878
Chickpea + mustard	459	983	1,935	1,328	794	2,520
Chickpea + wheat	811	1,244	1,514	1,368	852	1,749

\* in case of chickpea/mustard, row ratio was 4:1

Source: Singh and Yadav (1992)

Frenchbean has been found quite compatible for intercropping with early potato due to its high N requirement and wet moisture regime. Studies conducted at Kanpur showed that intercropping Frenchbean cv. Udai with potato cv. Kufri Chandramukhi in 2:2 row ratio (potato : Frenchbean) was highly efficient (land-equivalent ratio 1.59) and productive than sole crops (Ali and Lal, 1991). At Delhi, intercropping Frenchbean and potato in 3:2 row ratio gave the highest Frenchbean equivalent yield and LER (Ahlawat, 1998).

### HARVESTING, THRESHING AND STORAGE

Harvesting at appropriate time is necessary to avoid post-harvest losses. The maturity of different pulse crops varies considerably from region to region even for the same date of planting on account of atmospheric temperature, humidity, photoperiod, profile moisture etc. For instance, a variety of chickpea (ICCV 2) which matures in 90 days in south zone takes about 150 days in NEPZ and 165 days in NWPZ. When the stems and pods turn straw colour or light brown and the seeds are hard and rattle within pod, the plants should be harvested. In some of the crops like Frenchbean, pod shattering is a serious problem if harvesting is delayed. In other pulses too, over-ripening leads to fall of pods as well as shattering. At maturity, the moisture content of seeds should be around 15%. Seed cracking may occur if moisture content of seeds drops below 10% due to over maturity.

Harvesting is generally done by sickles. In some areas, hand pulling at physiological maturity is also practiced. Efficient combine is still lacking for harvesting and threshing of pulse crops. The harvested plants are carted to the threshing floor, dried for about a week and trampled under the feet, wheels of bullocks or under tractor or by beating with sticks. The seeds are separated from straw and trash by winower or dropping seeds manually from a height against wind current.



The clean seeds should be sun dried for 3-4 days to bring the moisture content to about 10%. Seeds should be safely stored in appropriate seed storage bins and fumigated to protect from insects.

#### SUMMARY

- The cool-season/winter (*rabi*) grain legumes comprising chickpea, dry peas, lentil, fababean and lathyrus contribute 29.7 million tonnes (48.3%) to the world pulse production. India ranks first in global pulse production and hectareage. The prominent *rabi* grain legumes are chickpea, lentil, fieldpea and lathyrus. Fababean and winter Frenchbean are minor crops. Pulses are grown on a variety of soils under different agro-climatic conditions and production systems. The states which have major share in nation's pulse bowl are Madhya Pradesh, Rajasthan, Uttar Pradesh, Maharashtra, Andhra Pradesh, Jharkhand, Chhattisgarh, Haryana, Bihar, Gujarat and Karnataka. Amongst various *rabi* pulses, chickpea occupies the prime position.
- The varietal development of pulses started as early as 1900. However, systematic and comprehensive programme on development of improved varieties of various pulse crops started only after the inception of All India Coordinated Pulses Improvement Project in 1966. Since then a large number of improved varieties have been released and production technologies developed for various agro-climatic conditions.
- For successful cultivation of pulse crops, a well-drained, deep sandy-loam to clay loam soil, free from excessive soluble salts with pH 6.5-8.5 is ideal. In general, pulses do not require fine seedbed except the Frenchbean. However, tillage requirements depend on soil type, moisture availability, preceding crops, method of planting and target.
- Most *rabi* pulses are grown on residual moisture and therefore, adoption of appropriate moisture-conservation practices is imperative. When pulse crops are to be grown after rice, deep ploughing is required to incorporate crop residues. However, in relay cropping of lathyrus and lentil no tillage is done.
- The seed should be free from diseases, insects damage and should have 90-95% viability with physical purity. To avoid fungal diseases, seed treatment with fungicides like carbendazim, thiram, captan etc. @ 2-3 g/kg seed is recommended. Seeds of pulse crops should invariably be treated with *Rhizobium* culture which enhances the biological nitrogen fixation. Multi-location studies conducted on *Rhizobium* inoculation have shown 10-15% increase in seed yield. Since the *Rhizobia* is crop specific only right type of culture meant for different crops should be used. Fungicides like captan, thiram, carbendazim etc. are compatible with *Rhizobium* culture. The sequence of seed treatment should start with insecticides followed by fungicides and culture.
- Planting time is the most important non-monetary input having profound effect on crop growth, phenological development, occurrence of pests and crop productivity. Environmental temperature governs the planting time. However, in rainfed areas, the moisture content in soil also determines the



sowing time. For most of the *rabi* legumes ideal time of planting is the second fortnight of October for rainfed areas and the first fortnight of November for irrigated conditions in North-western plains zone (NWPZ) and North-eastern plains zone (NEPZ). In Central and Southern zones, however, planting is advanced to ensure the optimum use of conserved moisture and avoid terminal drought. Planting of chickpea is often delayed after rice crop for which appropriate genotypes like KPG 59, PBG 1 and BG 372 should be used. Use of zero-till drill after rice helps in advancing planting and also reduces energy cost.

- Adequate plant population is a must for harvesting optimum productivity. This is more important for those crops which have low plasticity in canopy development. The ideal plant population for timely planted chickpea is 25-33 plants/m<sup>2</sup>, whereas for late-planted crops it is 40 plants/m<sup>2</sup>. The optimum plant population for timely planted lentil is 60-80 plants/m<sup>2</sup>, dwarf fieldpea 30-40 plants/m<sup>2</sup> and for tall pea 20-22 plants/m<sup>2</sup>. The optimum plant population for Frenchbean varies from region to region. In NEPZ, 25 plants/m<sup>2</sup> was found ideal for Frenchbean, whereas in CZ population of 33 plants/m<sup>2</sup> was optimum.
- Seed purity, seed size and germination percentage decide the seed rate of a particular crop. The bold the seed the higher the seed rate. The optimum seed rate for bold-seeded (25 g/100-seed weight) chickpea genotypes is 80-85 kg/ha, whereas for small-seeded (15-18 g/100 seed weight), it is 50-60 kg/ha. Under late planting, the seed rate is increased by 20-30% to increase the plant population/unit area.
- The depth of sowing is determined by soil-moisture content at the time of sowing. In rainfed conditions, deep sowing (8-10 cm) is recommended whereas under irrigated conditions 5-7 cm depth is adequate for proper germination.
- Application of right amount of fertilizers at right time through appropriate method helps minimizing the loss and enhancing the use efficiency. Pulses require small amount of externally applied nitrogen, as they meet their N requirement through biological nitrogen fixation but need adequate phosphorus and sulphur fertilization. For early head start, 15-20 kg N/ha is required. The phosphorus requirement of most of the winter-season pulses ranges from 40 to 60 kg P<sub>2</sub>O<sub>5</sub>/ha. The response to applied K is generally low. However, under K-deficient soils, response to 20 kg K<sub>2</sub>O/ha has been observed. Application of 20-40 kg S/ha results in significant yield gain in most of the winter pulses. Amongst micro-nutrients, positive response to application of Zn, Mo, B, and Fe have been observed.
- The ideal method of fertilizer application in pulses is placement of fertilizers in side rows at the time of sowing. Foliar spray of urea (2%) is recommended in rainfed areas.
- Contour bunding, deep ploughing, mulching and water harvesting for life-saving irrigation are the important moisture-conservation measures which should be adopted. On deep Vertisols, post-plant irrigation may not be required if soil profile is fully recharged at the time of planting. However,



in light-textured soils 1-2 irrigations at branching and pod development proved highly productive in most of the winter pulse crops. Care should be taken not to apply heavy irrigation as it adversely affects pulses. Frenchbean, which is cultivated only under irrigated conditions in plains, require 2-3 irrigations in NEPZ and 3-4 irrigation in central zone. First irrigation at 25 days after sowing (DAS) is most advantageous.

- Weeds compete with crop plants for applied inputs as well as natural resources, and as such may reduce the yield of winter pulses by 20-60%. The predominant weeds infesting winter-pulse crops are broad-leaf weeds and sedges. The degree of loss is determined by the nature and magnitude of weed infestation, which varies in different pulse crops. Initial 30-60 days are most critical for crop-weed competition. Hoeing or manual weeding at 30-45 DAS is effective in most of the pulse crops. Among chemicals, pre-emergence application of pendimethalin @ 1.0-1.5 kg/ha has been found most effective in the winter pulse crops. Soil solarization is also effective in destroying root propagules of weeds and their seeds. Integration of pendimethalin 0.75 kg/ha and one hand-weeding 30-45 DAS has been found efficient in chickpea, lentil and frenchbean.
- A number of pests attack *rabi* pulses. The prominent ones are gram pod-borer, semilooper, termites and cutworms in chickpea; aphids and spiny pod borer in lentil, and leaf miner, aphids and pea stemfly in fieldpea. Dusting the crop with carbaryl 5% dust or spraying with chlorpyrifos 0.07% or with botanical pesticides like neem-seed-kernel extract 5% or microbial product nuclear polyhedrosis virus (NPV) 250 larval equivalent (LE) are effective against pod-borers and semiloopers in chickpea. In lentil, the effective control of insects can be done by applying demeton methyl (0.05%) and dimethoate 0.03%. In fieldpea, stemfly, leaf miner and aphids could successfully be controlled through seed treatment with 2% phorate or soil application of phorate @ 1 kg/ha. Spraying with malathion 0.05% or monocrotophos 0.04% is also effective.
- *Rabi* pulses are infected with several diseases, the important ones being wilt, root rot, collar rot, *Ascochyta* blight, botrytis gray mold in chickpea; wilt and rust in lentil, powdery mildew, rust, damping off and stem rot in pea and bean common mosaic virus in Frenchbean. The control measures involve growing of resistant/tolerant varieties, following crop rotation, seed treatment with fungicides and foliar spray with chemicals like captan, thiram, carbendazim, mancozeb etc.
- Pulses are an integral part of the cropping systems and as such they are essentially required to be included in major cropping systems for sustaining the soil health and maintaining the productivity. *Rabi* pulses are grown as main crop, intercrop, mixed crop, relay crop or alley crop depending on the need of the locality. The prominent pulse-based cropping systems which occupy large area are: rice-chickpea/lentil, maize/sorghum-chickpea/lentil/fieldpea, rice-lathyrus, fallow-chickpea etc., and prominent intercrops are: chickpea + mustard/barley in north India, chickpea + linseed, lentil + linseed and chickpea + safflower in central India and chickpea + coriander



in south India. Relay cropping of lentil and lathyrus after rice is prevalent in Uttar Pradesh, Bihar, West Bengal, Chhattishgarh and Madhya Pradesh. The productivity of these cropping systems can be enhanced by following suitable agronomic practices such as selection of compatible varieties, fertilizers use, weed management, tillage and appropriate plant protection measures.

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